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VICTORIA EMBANKMENT, LONDON W.C.

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EDITED BY P. F. ROWELL, SECRETARY.

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CORRIGENDA.

p. 44, col. 1, line 13: For "ventilated" *read* "vertical".

p. 508, col. 1, line 25: For "is" *read* "as".

frontispiece.

John Snell.

PRESIDENT 1914-15

Keith Dannatt, photo.

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INAUGURAL ADDRESS.

By Sir John Snell, President.

([illegible])

Let me first express my thanks to the members for the honour that they have done me in electing me to be their President for the ensuing year. No greater honour can be conferred by the Institution on any of its members. I am fully sensible of the responsibilities which it entails. So far as in me lies I will devote myself to the interests of this great Institution, and to those of the electrical profession. It will require some measure of fortitude to keep the Session active under the present abnormal circumstances; but with faith in the ultimate triumph of our cause, every corporate body like this Institution must persevere in its normal and proper duties and must perform them faithfully and diligently. Carlyle has said, "Were he never so benighted, forgetful of his high calling, there is always hope in a man that actually and earnestly works—in idleness alone is there perpetual despair." Let us all work therefore, each in the best way he can, for the good of the King and country, for the good of the electrical profession, and for this Institution, confident that the increasing influence of the Mother Country and of our Sister Dominions across the Seas in the World's counsels, whether in scientific progress or in beneficent government, will be best attained by each of us doing the utmost he can to keep the industry in which he works active and progressive.

It is a difficult task to write an address without plagiarism on the one hand, or on the other without invading the region of controversy. A President is somewhat hedged in in this respect, for while he ought to draw upon his accumulated experience so as to give from his best to his fellow-members of the Institution, it is difficult to dilate upon the results of such experience without touching upon controversial matters.

My work for the greater part of my professional life has been among municipal undertakings, and it is natural that I should refer to some aspects of this branch of electrical enterprise. At the same time, only to do that and nothing more would be to address the members from a somewhat narrow standpoint, greatly important though municipal work is throughout the British Empire.

I cannot, however, fail to remember that I owe much to the Incorporated Municipal Electrical Association, on whose Council I had the honour of serving for so many years, and whose President I was in 1903–4. In the work of that rapidly growing Association, the influence of which is now unquestioned, and especially on its Parliamentary Committee, I served an apprenticeship which I am hopeful may be beneficial to me when dealing with the duties that lie before me here. I have had sufficient experience on the Council of this Institution to say that the duties of Members of Council become more arduous and exacting year by year. This must necessarily be so in such a body—the Cabinet as it ought to be of the electrical profession, a profession which is so catholic in its nature.

Development is increasing almost in a geometrical progression, and electrical engineering covers a vast field ranging from the useful application of great natural sources of power, as typified in the utilization of the waters of Niagara or other great waterfalls, to the development of wireless telegraphy and its immeasurable effect on the preservation of human life and property.

I can safely say that the Council whom the members of this Institution have honoured by their selection are prepared, in spite of these increasing duties which devolve upon them, to devote themselves to the interests of the members.

Some of us will remember the Holmes magneto-electric machines at the South Foreland and the De Meritens machine at the Lizard, the Jablochkoff candles on the Embankment, the Brush system of series arc lighting, and other early developments which were of the highest scientific importance. In 1879 there was an Exhibition of Electric Light Apparatus in the Albert Hall under the auspices of the then Society of Telegraph Engineers (the parent of this Institution) and the Council of the Royal Albert Hall. At this Exhibition gas-driven and steam-

driven electrical sets were exhibited, machines by Siemens, Gramme, Wilde, De Meritens, Holmes, and others; and the late Sir William Preece gave a lecture which is most interesting to read now in the light of the great developments that have since taken place.

Looking back to those earlier applications of dynamic electricity, we cannot fail to be impressed by the vast developments that have taken place in the 35 years which have passed since that time. Electrical machinery of enormous power is now common with efficiencies of only 1 or 2 per cent short of the ideal; the great development and flexibility of 3-phase machinery, the employment of very high voltages over great distances, the transmission of power of hundreds of megawatts, oceanic wireless telegraphy, wireless telephony, and the applications of electricity in surgery, represent only some of the world-wide applications of electricity which are leaving an ineffaceable mark on human progress and are helping to conserve the available energy in the world.

We electrical engineers have not the opportunities, it is true, of leaving great memorials behind us so monumental as a Sphinx, a Colosseum, a Forth Bridge, an Assouan Dam, or a Panama Canal. While, however, the results of our work are not so monumental in one respect, I venture to say that the cumulative effect of the better utilization of fuel and the avoidance of waste, the harnessing of natural sources of power which would otherwise be wasted, the diminution of smoke, the better facilities of transit, and the effect on housing problems and public health, the swift communication of news and its effect on political relationships, and the greater fraternization of peoples, the beneficent effects of telegraphy and its assistance to those in distress at sea—all these have, and will have, an effect on man and his progress which in itself will be monumental.

At such a time as this, when the nations of Europe have entered upon what is the biggest war yet waged, it may seem ironical to speak of the "fraternization of peoples." We will, however, hope that when Peace has again brought its blessings and relief, it will be more than ever the desire of the various nations to live in amity and friendly rivalry, without resort either to an enormous expenditure on armaments or to this titanic arbitrament of force, and that scientific peoples will assist mankind not so much to develop ingenious weapons of destruction, but rather to enable men to understand and appreciate more clearly the wonders of the Universe.

Electricity enables us to command the seas, through messages and directions sent to our glorious Navy, and to maintain communications with distant parts of this Empire. We thus obtain our food supply and maintain our trade, without which our whole social fabric would be paralysed. We may indeed be thankful that in this war which we did not seek, but which for our national honour and perhaps one may add for our existence as a great Empire we were obliged to undertake, the discoveries and experiments of Faraday, Hertz, Preece, Lodge, and Marconi, to mention only a few of those who have assisted to develop wireless telegraphy, have enabled such dispositions to be made by those in command as, it may be hoped, will more speedily bring to an end this calamitous struggle.

I should like, in the first place, shortly to review some of the work undertaken by the Institution.

Education.

Since the Articles of Association were revised in 1912 there has been a great increase in the work of the Institution. For instance, in the matter of qualifications all Students entering the Institution must now produce evidence of general education: and examinations have also been instituted for admission into the Associate Member class.

The regulations have been laid down on broad lines. Candidates who have already passed certain recognized examinations are not required to sit again for the Institution's examination, their diplomas or degrees being accepted as exempting them from further examination. Others who have taken degrees which demonstrate their general education are only required to take the second part of the Institution's examination, *i.e.* the engineering section. Others again who can demonstrate their general engineering knowledge by presenting a thesis on some applied electrical subject are not required to take the Institution's examination provided that the thesis presented is of sufficient merit, and that the candidate may also be orally examined on the subject of his thesis.

By these means the status of electrical engineers will become more assured. At present anybody may call himself an electrical engineer whether qualified or not, and it should be one of the objects of the Institution to ensure to the public that all corporate members of this Institution are properly qualified.

In the Institution of Civil Engineers the effect of more stringent requirements and of examinations has been undoubtedly good. The diploma is much sought after, and that Institution has now the privilege of nominating some of its corporate members for Commissions in the Royal Engineers and for positions in some of the Government Engineering Departments. In the course of time the Institution of Electrical Engineers, too, will be recognized in a similar manner, and I feel that the steps taken by the Institution will prove of the greatest value in time to all the members, and will have a beneficial effect on the status of the electrical engineer.

We have, in my opinion, a great duty to perform in insisting on a wider education being given to the rising generation. As Dr. Unwin remarked in 1911, "It is no doubt . . . due in part to the narrow and unscientific character of secondary and university education in this country, that until recently the education and training of engineers has been so unacademic and unsystematic." We have now recognized the necessity of requiring certain minima of acquirements in each candidate for admission to our corporate membership. We have endeavoured to combine practical training with academic training; a reasonable blend of both being what is wanted. I think that the requirements of the Institution will guarantee this result.

Papers Committee.

The Council have also taken steps to improve the arrangements for the selection and reading of papers. We shall gradually have ready before each new session a co-ordinated programme of the papers to be read in London and at the Local Sections. It is hoped that this will prove a great convenience to members, as it

will [illegible] particular subjects in which they may be interested to be noted in good time with a view to making preparations for a [illegible] contribution to the general discussion.

I use this opportunity to urge, and I desire to encourage, the younger members to [illegible] part also in the discussions which the paper deal with a subject in which they have had some particular experience. The object of reading a paper is not only to lay before the members the experience of the author but also to induce a discussion which will ventilate the subject thoroughly and thus diffuse knowledge.

SECTIONAL COMMITTEES.

Sectional Committees have been appointed by the Council, each dealing with a particular branch of electrical engineering, so that [illegible] the papers can be considered, authors invited to submit papers, and discussions arranged.

RESEARCH.

The Institution has now also taken up research. Here again valuable work can be done for the industry, and we are most grateful to those members who give so freely of their time to this work. Any results must necessarily take time to realize, but I am confident that they will be forthcoming, and that they will be of great value. We also feel grateful to the National Physical Laboratory for its valuable co-operation in this work.

INDUSTRIAL COMMITTEE.

Much criticism has been levelled against the Council on account of the formation of a short-lived Industrial Committee and its subsequent disbandment. It is really a very difficult matter to deal with, much more so than critics appreciate. Some of the matters referred to this committee were of a controversial nature, and to give decisions on controversial subjects affecting two sections of the industry which may happen to be opposed in their views must necessarily involve serious and sometimes insuperable difficulties.

In my opinion there must be, apart from the Institution, separate bodies who will deal with their own immediate and particular interests. The Incorporated Municipal Electrical Association, for instance, deals particularly with municipal interests, and has done and is doing splendid work. The British Electrical and Allied Manufacturers' Association deals with the commercial and industrial details of the great electrical manufacturing interests and has become a powerful organization. The Electrical Contractors' Association again deals with the contracting side of electrical work, more particularly consumers' installations; the Tungsten Lamp Association with metal lamps; and the Power Companies have their own interests to watch, and so forth. In certain cases the interests of two of these bodies may be diametrically opposed, and yet the members of most of them are united within this Institution. In view of this possible conflict of interests, it would obviously be impossible for the Institution to exercise functions such as those which the various sectional Associations so successfully carry out, each one from the point of view of the particular section of the electrical profession which it represents. On the other [illegible]

There is [illegible] between the Institution and any one of the sectional Associations. The Institution has [illegible] progress as a whole, while on the other hand each Association has its own particular sectional interest to advance. One can understand a position arising in which for example the Manufacturers' Association, in order to protect its members, might be obliged temporarily (it would [illegible] only be for the time being) to oppose the introduction of some improved design of machine. The Institution, however, untrammelled by any sectional interest and desirous of advancing electrical interests generally, would be rightly expected to encourage any such improvement. It is in that sense that there must be sectional associations apart from the Institution, and that the Institution must maintain a broad and impartial outlook over the whole profession and electrical industry.

We ought also to be well informed on all legislative matters affecting the use of electricity, to be prepared to assist Government Departments when required, and to make representations to them when necessary in the interests of electrical development.

The Council defined their attitude towards such interests in their last Annual Report, wherein it was stated that "the Council will in future, as in the past, within the provisions of the Memorandum of Association, take such action in respect of legislative or industrial matters as may conduce to the general advancement of electricity and its applications, and will give full consideration to any representations made to them while preserving impartiality to all sections of the electrical industry." I think all members, except perhaps a few extreme sectarians, will desire that the Council should preserve an absolute impartiality towards all sections of the profession; but that must not be interpreted as standing aloof and doing nothing to promote the interests of the profession as a whole.

I think some organization can be created which will be constantly ready to consider any question that may arise from among the many sectional interests which the Institution incorporates. The most flexible organization that I can suggest is the formation of a standing Advisory Committee, composed, say, of the President, three Past Presidents, and three Members of Council. There must be, first, some continuity of action on the part of such a Committee, and that is why I suggest that some of its members should be Past Presidents, otherwise the Committee would be continually changing in its personnel. On the other hand, three Members of Council and the President for the time being would bring in fresh blood. This standing Advisory Committee might be given power to add to its number, choosing from among other members of the Institution. I do not know, of course, how this suggestion will commend itself to the Council, and it must be understood that I am only expressing my own opinion.

Suppose a Government Bill be brought in to amend the Electric Lighting Acts, I would suggest that the draft Bill should be referred to the Advisory Committee for report, the Committee thus acting also as a Parliamentary Committee. A few outside Corporate Members or Associates would be invited to join them *ad hoc*, and so a strong committee,

including these specially co-opted members, would deal with the particular subject: and when the particular work was done the co-opted Members or Associates would be released from their duties, though the nucleus Committee would remain.

Or again, suppose a difficulty were to arise between two sectional Associations, and suppose the Council were invited by them to compose the difficulty. The Advisory Committee would again invite certain members fully experienced in the subject in dispute to join them for the time being; and thus the best thought would be brought to bear on the subject. Conferences with both parties could be held, and it may be hoped that either a fair compromise would be arranged or a direct report made to the Council that some definite attitude should be adopted by them and that the Institution's influence should be directed in some specific direction.

The ultimate power to act must of course rest with the Council, who clearly cannot delegate their powers and responsibilities to another body. Much time would have to be given by this Committee to the interests of the Institution in order to do effective work, and the duties would certainly be heavy; but if the result is likely to be good there are many among us who would give our services freely.

In my experience it has always been the desire of the Council not only to get thoroughly representative members elected from every branch of our industry, but also so far as is possible to have proper regard to geographical distribution. It must not be forgotten in the latter case that each Local Section sends its Chairman and its immediate Past Chairman to the Council. Thus geographical distribution is to this extent at once assured, though of course other provincial members are often nominated and elected to the Council. On the other hand, members living at a distance cannot give that continuity of attendance which is necessary for effective work. The greater part of the work must thus necessarily fall on members residing around London, and in the Advisory Committee which I have outlined the nucleus would probably have to be formed from London members; but specially co-opted members could be drawn from any district.

I am convinced that every one of us is anxious to devote himself to the general well-being of the Institution and its members so long as the Council maintain a broad and impartial outlook over the interests of the whole and do not allow their judgment and influence to be weakened or narrowed by sectarian interests to the possible injury of the general community.

Organized Lectures.

It has been suggested that the Institution could do good work by organizing lectures in various parts of the country so as to educate people in the applications of electricity to various kinds of industrial power, or in the advantages of electric lighting or of electric heating and cooking. I do not for a moment say that all proper means to develop the use of electricity should not be adopted, but it would seem from my past experience that lectures and demonstrations can be best dealt with by local organizations, such as the municipal and company-owned electricity undertakings and their commercial departments. I think they are then more effective.

A good deal of work is undertaken which might appear at first sight to be abortive. For example, in 1911 the Council were invited to form a Textile Committee to investigate the subject of the electric driving of textile mills, and some of us took considerable pains to get in touch with the Textile Institute and became members of it. The Committee was duly formed from the two Institutions with the object of inquiring into the question and seeing whether a report then just issued, and rather advocating steam driving to the exclusion of other systems, was founded on sound observations and results. We had several meetings in Manchester, but they came to nothing and the Joint Committee was disbanded. Why? Because the Textile Institute desired—and, I think, quite properly—to cover a wider field and to inquire into the relative merits of all available prime-movers, whether electrical, steam, gas, or oil. The work of the Joint Committee, however, was not in vain: it awoke the Textile Institute to action in this respect, and in the meantime several mills had changed over to electrical driving and the results of their experience formed a better advertisement than a report from any Joint Committee.

Model General Conditions.

One good piece of work has been recently accomplished by the issue of the new "Model General Conditions for Contracts." It involved the special Committee appointed, as well as the Council, in an immense amount of work. There were protracted negotiations with bodies like the Manufacturers' Association, the Municipal Electrical Association, and the Association of Municipal Corporations; also drafting and re-drafting by counsel, as well as other labours. I myself think that these Conditions establish a very fair relationship between the Purchaser, the Contractor, and the Engineer, respectively; and it may be hoped that they will find general acceptance and adoption.

Remuneration of Young Engineers.

In what way can the Institution help the younger men? The Council have been asked at various times to assist in finding positions for their younger brethren and to regularize and improve the status and pay of young engineers. In a general way, and in time, the improvement in the status of Associate Members, due to the system of examinations and the qualifications now necessary, will have a good effect in this direction. I do not see, however, that the Institution can very well become either a Trades Union or even a Labour Bureau.

That there are serious causes for complaint from the younger electrical men, I am certain. Let us look for a moment at some of the causes. One of them is supply and demand. If, for example, a vacancy for a junior occur in a power station, the moment the post is advertised there is a crowd of applicants, with the result that the next time a similar vacancy occurs the salary offered is sometimes less than before. That, undoubtedly, is one cause of low salaries. I would ask fellow-members who are Heads of Departments to do this—to give so far as is reasonable and proper a preference to applicants who belong to the Institution (in a very short time this qualification should be indispensable); and in fixing salaries do not think so much of recording a small fraction of a penny less per unit

[illegible] spent on theoretical training and not enough on practical [illegible] technical colleges.

I hope that as the result of the various remedial forces now at work the remuneration of electrical engineers during the earlier stages of their career will soon be improved.

NATIONAL SERVICE.

It is fitting that I should refer, in such times as these, to the splendid and loyal response made by hundreds of our members to the call of our Sovereign and to the defence of the Empire.

When our immediate Past President, who rendered most patriotic and untiring service to this cause, circularized the members of the Institution at the instance of the specially appointed National Service Committee, a very large number of our members of all classes—nearly 500—offered their services. A very large majority volunteered either for service at home or abroad. Acting in company with the President and Secretary of both the Institution of Civil Engineers and the Institution of Mechanical Engineers, it was first suggested that these three Institutions should form an "Engineering Institutions" Battalion for service in the field, and that we should clothe, house, feed, and train the recruits, so that when ready the battalion could be handed over to the War Office in a condition of complete readiness. The Institutions of Civil and of Mechanical Engineers readily gave the weight of their influence to the movement, and in our own case we are particularly indebted to one of our members, Major-General R. M. Ruck, C.B., R.E., for his invaluable counsel and assistance and for his influence at the War Office.

There then came an unexpected proposal that the three principal engineering Institutions should recruit the Engineer Units for the Royal Naval Division, just then authorized to be formed. The response from members of all classes of all three Institutions was so spontaneous that the corps was formed within a few days by men not only of splendid physique but also of highly skilled intelligence, professional men trained in various branches of engineering, and forming a personnel of the highest value to the Admiralty. All three Institutions owe Mr. W. Duddell, F.R.S., Mr. A. P. Trotter (who was one of the originators of the movement), Mr. Robert Hammond, Colonel D. E. Ruck, R.E., our Secretary, Mr. Rowell, and the Staff of the Institution, who were all indefatigable in their labours as recruiting agents, a great and lasting debt for their untiring [illegible] addressed to all the then members, associates, and students, resident in Great Britain and Ireland. When the replies [illegible] the question, and in June 1896 a meeting took place at the Horse Guards between this Departmental Committee and the Institution's Volunteer Service Committee. Their joint recommendations were subsequently approved by the Secretary of State, provision was made in the Army Estimates, and Dr. John Hopkinson was appointed to be the first commanding officer. The first training took place in the autumn of 1897, and during the following year over 100 volunteers were enrolled.

At a Council meeting held in October 1897, it was agreed that in view of the desirability of this Corps remaining identified with the Institution certain official assistance should be given by the Council. Later, at the time of the South African War, the Corps having volunteered to provide a contingent for active service in South Africa, and this offer having been accepted by the War Office, the Council appointed an Advisory Committee consisting of Professor J. Perry, Mr. R. P. Sellon, and Mr. Alexander Siemens, to assist Lord Kelvin, then the Honorary Colonel, and Colonel (then Major) Crompton, who was in command, in the purchase of field plant. Members of the Institution subscribed towards this fund, and in 1900 the fully equipped contingent embarked at Southampton for South Africa and served their country in that campaign. No less than 330 out of a total strength of 500 did their part in this way.

The Electrical Engineers (Territorial) R.E. battalion is in the King's service to-day, and the members of it are on duty under the command of my old friend Lieut.-Colonel Le Rossignol, R.E., at several of our important defence works. It was only the other day that one of the officers of the Corps wrote to ask me if the Institution's influence could be exerted to enable some of them to go to the front—over 70 per cent of the officers and men having volunteered for active service. When the time is ripe for it, we shall without doubt do all we can to assist. Many of our members are also serving in the Signalling Corps of the London Army Troops under Colonel E. H. [illegible] men able to utilize their skilled experience in [illegible] and wireless services.

Many others of our members have also joined other regiments. The Institution will be proud not only of its own Battalion of Electrical Engineers and of those electrical engineers serving with the Signalling Corps and elsewhere, but will feel great pride also in the members who have so

freely volunteered for the Engineer Units of the Royal Naval Division. Let us wish them all from our hearts God-speed, and may their skilled services be of the greatest assistance to our forces and the greatest confusion to the enemy. When they come back, having done their duty as we know they will, we shall want to show them in appropriate ways how proud we, as their fellow-members, are of them. May we not begin by recording all their names on an Institution's Roll of Honour?

Legislation.

Let me next review shortly the position of electrical legislation. It is well known that the Electric Lighting Act, 1882, is the parent Act affecting our industry, altered in one most important particular by the Act of 1888, that is, in the period during which a Provisional Order is operative, and extending the date of purchase on "then value" terms from 21 to 42 years. This 1882 Act as amended in 1888 gives any electrical undertaker not being a local authority a franchise for 42 years, and contains a number of clauses protecting existing interests and consumers' interests both as to supply and as to price. It was strictly parochial, afforded no facilities for giving a supply outside the specified area, or for co-operation with other electrical authorities.

The various later Power Company Acts gave wider powers both as to area and as to facilities to those companies, though otherwise partially restrictive, since a supply was to be given mainly for power purposes and only for lighting to a limited degree with the consent of authorized distributors, or in later Acts up to an amount not exceeding 10 per cent of the total energy supplied for power. Provision as to bulk supplies to authorized undertakers was incorporated in these Acts. Then followed the 1908 (London Electric Supply) Act, which afforded facilities for carrying transmission mains across intervening areas, with an appeal to the Board of Trade in case of unreasonable refusal on the part of any local authority. In this Act authorized undertakers were enabled with the approval of the Board of Trade to enter into agreements for mutual assistance in the giving and taking of a supply of energy and in the distribution of such a supply, and also in the management and working of generating stations or any parts of the several contracting undertakings, as well as in financial adjustments consequent upon such agreements. Protection was also afforded by this Act to undertakers in the supply to premises having a separate and independent source of generation.

The 1909 Act was then passed, which gave authorized undertakings a right to supply outside their area and on its fringes, and to supply in bulk—that is, to co-operate with other authorities, and to supply consumers whose premises or systems, such as canals, railways, and tramways, were partly within and partly without the area of supply. The stand-by clause was also by this Act made obligatory upon all past or future undertakings, and constitutes a protection to all authorized suppliers. Greater flexibility is thus now given to electric suppliers than formerly, but no case has of course yet arisen from which an indication can be gleaned of what will be the interpretation of the terms of purchase. Tramways purchase procedure will no doubt have some effect on the interpretation to be then given, and this is that the value must be that to the seller, based on the cost of replacing the plant and mains, etc., as they are at the time of purchase, but reduced by an amount for depreciation having regard to the then ages and the estimated useful lives of the component parts. The Electric Lighting Act terms are, however, enlarged as compared with the tramway terms, though the basic principle will be no doubt somewhat the same, in that allowance has to be made for the undertaking's being in a condition ready to supply, and an allowance for severance has to be made if the municipal and electrical areas are not the same. Thus some difficulties will no doubt arise when the purchase of the earlier undertakings falls in in 1924, and there will be plenty of work then for the Bar, and also for a few of our members.

Except in the further facility needed to allow undertakers to establish showrooms and to let fittings on hire, with due regard to the interests of electrical contractors, one does not see that much improvement can be suggested on the present laws affecting the supply of electricity.

In spite of what I have said, I feel that the suggested Advisory Committee might review the present legislative position, compare it with the legislation affecting water and gas undertakings, and see whether there are any further facilities or improvements which could be enacted, such as the "protection of property" clause, for example.

Items such as the hiring-out proposals, facilities for wayleaves where consent is unreasonably withheld, and so forth, are matters for the consideration of such a Parliamentary Committee.

It is unfortunate that the electrical profession has not some members in Parliament to represent it. As things go nowadays, unless there is at least one active Member to voice the wishes of a particular industry in Parliament, there is owing to pressure of other Parliamentary requirements small chance of any useful measure being speedily passed. Perhaps a few of our members will volunteer and offer themselves at future elections.

The Electric Lighting Bill which it is the desire of the Municipal Association to have placed on the Statute Book is one of very great importance to the whole industry. The Bill, as now drafted, is receiving the support of the Manufacturers' Association, but I understand that the Contractors' Association does not approve of it. I have carefully read the Bill, and, speaking from an entirely detached and independent position, I cannot feel otherwise than that non-agreement is regrettable and contrary not only to the public interests, but to the interests of the contractors themselves. Contractors will not be competed with by the supply authority in any wiring contracts, since the proposal is that undertakers "shall not themselves execute the wiring of private property," but they will be placed in competition undoubtedly in "providing, selling, letting on hire, fixing, repairing and maintenance of fittings, apparatus and appliances for lighting, heating, and motive power," though there are proper safeguards to prevent the public authority from undercutting contractors.

I am not of course in possession of what negotiations have taken place between these two important electrical associations, nor do I know what are the actual matters outstanding which prevent them from arriving at agreement. I suppose that supply authorities do not want to

make profits out of the sale of apparatus, to [illegible] to increase the output and revenue from energy sold; at the same time, as commercial undertakings, they [illegible] put their customers [illegible] of advertising and canvassing, etc., in the most favourable position. Surely a reasonable compromise could be arrived at which would be mutually advantageous. Increase of business should be the [illegible] direct result of the passing of a bill of this nature and therefore more wiring contracts.

This is a case where, in the public interest and in the general interest of the whole electrical industry, the addition of such a measure to the existing Electric Lighting Acts would appear to be of immense value to all interests —municipal or company undertakings, manufacturers, and, in my opinion, contractors. A way should be found to pass it in a form which would bring the greatest benefit to contractors as well as to the supply authorities.

Let me now turn for a time to some of the problems which are constantly before us and with which one is often called upon to deal. There are three items which may perhaps be usefully discussed, though I can on this occasion only deal with them very briefly. They are: (1) Bulk supply; (2) Domestic electricity; and (3) Probable future prices to consumers.

Bulk Supply.

Take first the question of bulk supply. I do not want now to enter into the matter controversially, and will deal only with what I think are facts. There is no doubt, were we beginning anew, that instead of each small local authority putting down an independent power station, considerable waste of money and fuel would be avoided by establishing one large system for several adjacent areas supplying energy to each smaller area for local distribution. Even in some cases where there are existing small power stations, some of them unfavourably situated for cheap generating costs, it would probably pay to extend one of the better placed stations only and to supply the others therefrom rather than to extend each local station from time to time.

I have a case in point where there are four smaller electrical areas abutting on one larger area, all within a radius of six miles and each having its separate plant. In each of these smaller places the power stations are not favourably situated either for coal supply or for water; the fifth and largest place, however, has a waterside station. In this case, concentration at the larger station with the consequent advantages of larger units of plant, smaller capital outlay, and cheaper costs of production, would far outweigh the extra costs of transmission cables and transformer plant and the losses in transformation. Unfortunately, however, there are the somewhat narrow views of some of the local engineers and local councils, which prove to be serious obstacles. This is regrettable, for in this particular case the extension of each little system entails waste when compared with the alternative scheme.

While this is often true, there is, however, another side to the question. It may be generally said that once a small station is built and the expenditure has been incurred, then and so long as the system is kept within defined limits of extension, the *extra* operating cost of an addition to the local power station is often cheaper than any commercially feasible bulk supply. I have had to enquire [illegible] the local plant, [illegible] commercial alternative was possible.

A case arose a short time back where a comparatively small station [illegible] The annual load factor, [illegible] load, was [illegible] per cent. A neighbouring large supply undertaking offered a bulk supply at very low terms—far lower than any terms yet mentioned [illegible] It was impossible to demonstrate that it would pay to purchase all the energy locally required from the bulk supplier, because of the [illegible] effect of the capital outlay and the standing charges on the existing local plant, which of course had to be paid whether the bulk supply were taken or otherwise. It was difficult to show any economy from the bulk supply when compared with the extra operating cost resulting from an extension of the local plant. Finally, the best terms were made for both parties by the local station undertaking to run its plant for one shift during only four months of the year, thus entirely taking the local load off the winter demand of the bulk station—that is to say, a co-operative system such as was proposed in the original London County Council schemes seven years ago.

I am firmly of opinion that no economy can be shown in the generality of cases where there are modern and properly managed undertakings whose capital expenditure on buildings and plant is not yet redeemed or written off, unless energy can be supplied by a bulk authority at rates not exceeding £2 10s. per kilowatt of maximum demand and 0·25d. per unit delivered for untransformed high-tension energy. In many cases the bulk figures would even have to be lower. We hear much of the benefits of bulk supply—there are benefits in certain cases, admittedly —but committees are often misled by receiving a proposal to pay £3 per kilowatt and 0·25d. per unit sold to them, which at first sight, when resolved into the particular price per unit, appears to be so much less than the local costs of generation. It is not always understood by the committees, or even by the public or non-technical Press, that many additions have to be made to the bulk figure before a proper comparison can be made with the local costs. In the first place the units sold by the bulk authority are equivalent not to the units sold by the local authority, but to the units metered at the local authority's power-house switchboard; and to these must be added the units lost in conversion or transformation of the energy supplied in bulk as the case may be, together with the capital charges on the requisite transformers and extra switchgear, an allowance for wages (a considerable reduction, of course, on the wages at the local power station), and some allowance for repairs and maintenance. That increased figure divided by the number of units sold by the local authority represents the cost of generation only; which must first be converted into terms of "per units sold," and then the other general figures—distribution, rates and taxes, management, insurance, and all the capital charges on the local undertaking—have to be added before the final and comparable figure is reached. When these other additions are made it is found that the bulk authority's figure is, of course, considerably enlarged.

It may be said that this is all common knowledge; so it ought to be, and yet one often finds that comparisons

are wrongly made between the quoted bulk figure and the local cost. Such unskilful comparisons are injurious to the public interest, disseminate false ideas, and cause much trouble.

While this problem of assisting existing local stations from a bulk authority gives rise to these difficulties, and is one not so commercially helpful as at first sight appears, it is generally true that a new local area about to install an electrical system would do well first to obtain terms from a reliable bulk-supply authority, if available, before deciding to build a local power station. Better still, in many cases while the local authority would find the capital to build its local sub-stations and to lay its distributing network at probably cheaper rates of interest than a bulk authority can raise money, it can reduce expenses to a minimum by arranging for all the administrative work and upkeep of the local system to be undertaken, under proper supervision, by the bulk authority, the local authority only collecting the revenues.

What we all desire to see is electricity sold at the cheapest rate and at a reasonable profit to consumers whether of the industrial or residential classes, at the same time to avoid waste of capital and not to incur unnecessary working expenses. Such a policy means more consumers, greater output, more plant and apparatus, and is good for the industry and for the nation in every way.

Whether any local undertaking should extend or whether it should purchase energy in bulk is a matter which can only be determined after careful investigation, and this question cannot be settled by any general policy. Each case must be decided by local circumstances of capital invested, costs of working, load factor, and other details.

The Local Government Board, which controls to a limited extent the expenditure by the various municipal electrical undertakings that represent the great majority in this country, could do much in this direction. The application for a loan to carry out an extension by a local authority is so often delayed through one reason or another that by the time the Local Inquiry is held there is no time left to consider any alternative, and in the immediate public interest sanction has to be given to the scheme then put forward. In the national interest, and therefore in the ultimate interest of the particular local authorities concerned, I should like to see a complete survey made by the Board of the present position of all the electrical authorities, so that in those cases where amalgamation of electrical interests, or purchase of energy from some outside source for local distribution, ought rather to be adopted in lieu of a local extension of plant, the Board would decline to sanction any loans for the proposed extension of local plant.

A thorough survey of the position in this manner, and consequent action on the lines suggested, might not only save public money but would also conserve our stores of coal and therefore be of ultimate service to the community. Moreover, it would enable the public systems thus to supply consumers on the most favourable terms. I do not at all say that this can be done universally, but I do know that there are several groups of undertakings where concentration on the lines which I have suggested would produce economies. Perhaps the Local Government Board will take this matter into their consideration when we have again settled down to normal circumstances. The Local Government Board, I know, use every endeavour now to see that capital is judiciously expended by electrical authorities, but I think they can go further and enquire whether the proposal to extend local plant is the wiser course or not. Information can only be obtained by a thorough investigation into all local undertakings, which when once reviewed could be kept up to date from year to year. This survey would be of the utmost value to the Board's Inspectors and would be referred to by them when reporting on any particular application.

Domestic Supply.

Another matter of great interest to us all at the present time is the domestic supply. To my mind it is an unnecessary cost to the consumer and a brake upon progress to require two sets of wiring in any one residence. The supply for lighting on the one hand, and for heating and cooking on the other, should not be differentiated in the consumer's installation. Let us endeavour to remove all unnecessary barriers to a generally increased use of electricity. One meter and one set of apparatus generally would then suffice, with a consequent less cost per service to the supplier.

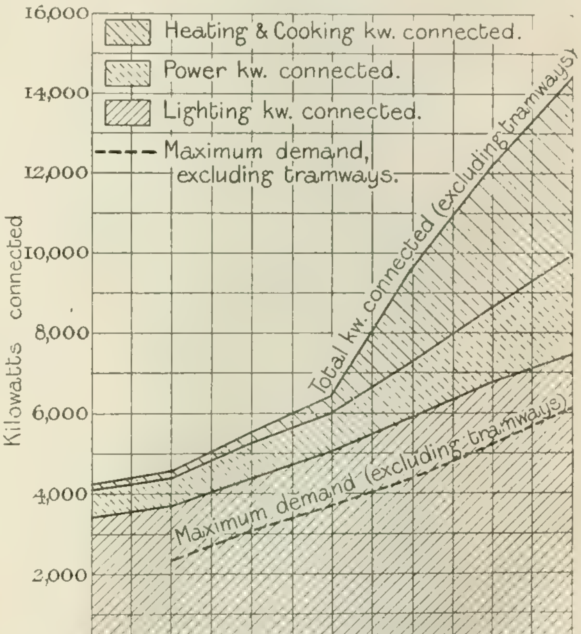


Fig. 1.

Electric lighting, since metal-filament lamps came into practical use, is very cheap—in fact at the average rates generally obtaining, almost unnecessarily cheap—though the load factor is better now than in the days of carbon-filament lamps, and electricity can therefore be supplied more cheaply than when the tariffs were originally fixed.

I have had during the last two years to enquire exhaustively in more than one instance into the cost of supplying electrical energy for heating and cooking. It is a fact that there is a very great diversity indeed between the lighting and cooking loads, whether in London or in the Provinces. Fig. 1 reproduces an actual case. While the lighting and

[illegible]

to 37 per cent for comparable days in three successive years, [illegible] the winter, and this result would have been expected. [illegible] have also been obtained in other districts. Individual [illegible] domestic supply must be expected and must be provided [illegible] find that the ratio of other domestic units to the lighting [illegible] residences in one provincial town gave a ratio of 3·5 to [illegible] therefore there may be a London district here and there where the domestic supply may in the future be 11 times as great as now, it is quite certain that to adopt such a multiplier all round would be greatly to overestimate the probable requirements. It is quite probable, however, that in the near future existing consumers who now take energy only for lighting or heating to a very limited degree will be purchasing from 4 to 5 times the number of units metered at present. This will mean a very greatly increased output and improved load factors. Increased load factor and larger output will react on and reduce the costs of production. Increased output of utensils and apparatus will reduce their cost also, coupled with the [illegible] efficiency and durability. All of these factors are favourable to a greatly increased use of electricity.

What we also want to ensure is that not only is the energy supplied to consumers at the lowest practicable rates, but that the first cost of installation is also reduced. Initial outlay is usually the greatest deterrent to the adoption of an electrical supply. Let us therefore adapt our systems so as to simplify things as much as possible. Why should a consumer have to pay for two separate and complete wiring systems in his house? In some larger premises of course that might prove to be the cheaper thing to do, but among the general consumers—small residences, shops of moderate size, and so forth, which after all represent the great majority—a single system of [illegible] unit for domestic supply; but the [illegible] that [illegible] based on the rateable value, plus the running charge per [illegible] down to three kinds, namely (1) The assessment system [illegible] because they are more readily and justly adaptable to the various domestic needs, whether lighting alone, heating alone, cooking alone, or any combination of them.

The supply of industrial works is now so well established that that branch cannot fail to continue to make steady and good progress. Modern works of all kinds—even mills with annual load factors of over 60 per cent—find themselves obliged to adopt electrical driving. It is the domestic supply which will, however, provide the bulk of the business in many of our towns; and to this service the thoughts and energies of electrical suppliers are and must be directed. Outputs far in excess of any that we have yet reached will then be obtained. Such an expansion is good not only for the electric supply authorities but for the electrical trade, by increasing the number of wiring contracts, and the trade in lamps, heaters, and other utensils, thereby increasing the demands on the manufacturers both for domestic apparatus and also for cables and generating plant.

Every encouragement ought to be given by the Government, by health authorities, and by the public to the more general use of electricity for domestic purposes. It has, and cannot fail to have, a marked effect on the pollution of the atmosphere, on fog, and on public health, and it is therefore of national importance. It has a marked effect on property by minimizing fire risks and by reducing the corrosive effects on buildings and structures. We may hope, therefore, that with the now active commercial attention given to all these matters by our electrical undertakings, the already marked acceleration will be further increased, as there is evidence to show is the case.

The electrical industry cannot fail to make great progress, because our resources are improving. Cheaper plant, generation on a bigger scale at cheaper costs, improved consumer's apparatus and lighting, cheaper domestic apparatus, all go to reduce the cost to the consumer, and necessarily an ever-widening area of operations is obtained. Let us reduce to a minimum the cost of installing premises, and this growth will be yet more rapid.

[illegible]

What will be the probable future cost of electricity in this [illegible]

such as a farthing per unit, and even one-eighth of a penny. To my mind it is unwise to speak loosely of sensational figures like these unless there is substantial evidence to support them. That the present cost of electricity to various classes of consumers, whether domestic or industrial, will be further reduced in the future, no electrical engineer will deny. What are the prevailing figures now? Energy for domestic lighting costs, say, 2½d. per unit; the cost of power varies from 1d. down to ⅓d. according to the load factor, size, and kind of supply (*i.e.* whether transformed and converted, or untransformed high-tension energy). Special supplies are given under exceptional circumstances, such as restricted hour, non-peak loads, at still lower rates such as 0·15d.; these, however, may be termed by-products. The average cost to the consumer in this country is now 1·56d. per unit, and in London it is 2·15d. I do not know any other country that can show as good figures, except in one or two instances of exceedingly large supplies to railways and traction systems.

It may be worth while to consider what possibilities lie before us so far as we can now foresee; but we must clear the ground first. Are we to expect amalgamations on a big scale, or power stations operating over county areas or even still more extended areas, or are we to expect a continued development of many separate power stations in such an area?

I have already indicated the necessity for amalgamation in some special cases of adjacent small electrical areas. Can this be usefully extended in Great Britain to any large extent? There is certainly a marked tendency on the part of the larger cities, such as Manchester, Glasgow, and Birmingham, to sell in bulk to their neighbouring and surrounding towns and districts, and, I am glad to say, a better disposition on the part of such smaller districts to take the supply from their larger neighbours. Fear that the electrical supply is the "thin edge of the wedge" of complete municipal absorption by the larger city represents one of the principal obstacles, and there is the difficulty at the present time, already pointed out, that where a power station is now in operation in the smaller area, it is very difficult—almost commercially impossible in some cases—to offer bulk-supply terms that will be cheaper to the smaller authority than the extra cost (on existing costs) of a local extension of plant.

The power companies operate over wide areas. It has proved to be very hard work to build them up; and to be quite frank, very few of them can be said as yet to be in a really sound financial position. They have done valiant work—it has been my good fortune to investigate the position of more than one of them in great detail, and I can testify to the unflagging efforts and the skill shown by the staff. I also know of some of the difficulties encountered. The fact that the principal towns already have their own power stations, the desire of the municipalities to have electrical undertakings under municipal control, the difficulties of obtaining wayleaves for transmission lines, the capital cost of transmission, together with the cost of money itself, have all been, and still are, obstacles to the development of such large areas of operation.

Some of these difficulties are yielding. It is noticeable that many local authorities are now more disposed to consider the alternatives of bulk supply and local extension when further plant is needed, as I have already said. The cost of transmission by cables at high pressure is very much less than it was a few years ago. The Board of Trade helps, so far as legislation now permits, in the development of overhead lines. As time goes on and these power systems extend and their gross profits show a larger percentage on capital expended, we may then hope that it will be easier to raise money and that there will be a better density factor on mains and lines. The position of the power companies will be then much easier, and the growth will be more rapid.

There are so many factors to be considered that without considerable sacrifice of capital and a complete change in public custom and opinion, one cannot reasonably look to the whole electrical supply in a province being given by one system. Undertakings above a certain size and output are bound to continue independently. Faraday once remarked that we must be "not too hasty to generalize, and above all things willing at every step to cross-examine our opinions." This is wise counsel, and after due self cross-examination I still hold the opinion that in this country the local undertakings in the majority of cases will not be merged in larger and widely distributed systems.

Let us suppose, however, an ideal case of generation on a large scale from power stations dependent on fuel transmission to various parts of an extended province, partly by overhead lines, partly by high-tension cables, the transmission pressure being, say, 30,000 volts. Suppose, further, that the output embraces a supply to transportation systems (railways and other traction systems), wide classes of industries, such as chemical works, collieries, mills, shipyards, engine works, and also that the domestic supply reaches the extended application which I have suggested. The resultant average annual load factor at the power stations might then possibly reach 50 per cent. It seems to me physically impossible to expect a higher resultant figure over the whole generating system. Some of the power stations (I am assuming that there would certainly be more than one), might have a higher load factor, others less, but the all-round average might conceivably reach 50 per cent. The undertaking (assuming well-chosen sites on which no unnecessary expenditure on foundations, river walls, and piers would have to be incurred), equipped with large generating sets and simple inexpensive buildings, could be erected for about £8 per kilowatt installed. That must be considered to be absolutely a minimum, and I doubt whether such a figure could be even reached at the present time.

The detailed cost of such a power station can be taken typically as under:—

	£
Land, river walls, and sidings	0·25
Buildings, coal silos, foundations, cranes, etc. ...	2·00
Boilers, economizers, coal and ash plant, shafts, and mechanical draught plant	3·25
Turbo-generators, condensing plant, air filters, pipework, tanks, and switchgear	2·65
	£8·15

The generating costs *per unit delivered to high-tension feeders* at a 50 per cent load factor would probably not

[illegible]

[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
Total cost per unit sold	[illegible]

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]
Lighting	[illegible]	[illegible]	[illegible]
Heating and cooking	[illegible]	[illegible]	[illegible]
Power ...	20	[illegible]	[illegible]
	[illegible]	[illegible]	
	30	[illegible]	
Public lighting	[illegible]	[illegible]	[illegible]
Special power, *e.g.* mills	[illegible]	[illegible] to [illegible]	[illegible]
[illegible]		Down to 0·15d. according to load factor and other circumstances.	

These costs for various load factors are shown graphically in Fig. 2.

[illegible]

[illegible]		
[illegible]	[illegible]	
Other generating costs	[illegible]	
		[illegible]
[illegible]	[illegible]	
[illegible]	[illegible]	
		[illegible]
[illegible]		[illegible]
		[illegible]

The two principal items of costs are, therefore, fuel and [illegible]

[illegible] average charges to lighting consumers would still have to be 1⅛d., while industrial consumers with ordinary load factors would have to pay prices ranging from 0·66d. to ½d. if the costs were properly apportioned.

Or, again, suppose the capital cost of the complete [illegible] in the above figures, which would mean only £4 per kilowatt installed for the power house, and £12·5 per kilowatt installed for the sub-stations and mains (figures one may safely say cannot in any reasonable probability be ever reached), still the average cost of a 50 per cent load factor would be 0·42d., and the lowest permissible charge to a lighting consumer would be 1½d., and to an ordinary industrial consumer from ⅝d. to ½d. Thus we see the probable limitations of the reduction in cost of electrical energy supplied from power stations other than hydro-electric systems. In the latter the capital cost is generally the important factor, and the cost of production may be as high as that in a large steam-driven station.

As I have said before, it is therefore most unwise to talk about giving a general supply at ¼d., or even ½d. per unit. It is easily demonstrated that such figures are unattainable with any known methods, or from any developments which seem to be within the region of possibility.

People who do not study the question confuse the average price of some undertaking enjoying a high load factor (often omitting all reference to capital charges)

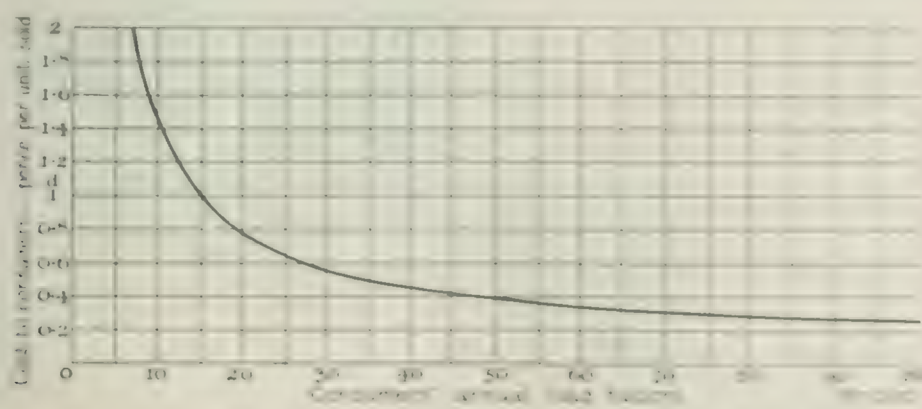


FIG. 2.

with the differentiated costs to various classes of consumer. The latter represent a very different set of figures.

By recognizing what are our limitations we know both our strength and our weakness. In my opinion it is foolish to speculate on figures which are really unattainable. The figures that I have quoted, however, are such as to give great encouragement to supply authorities, and to industrial and domestic consumers.

In a paper which I read in 1904 before the Institution of Civil Engineers* I then forecasted some figures, and it is interesting to compare those given 10 years ago with the estimate now framed. The comparison is as follows :—

	1904		1914
	Inst.C.E. Paper	Corrected to 50 % Load Factor	
Estimated annual load factor	25 %	50 %	50 %
Cost of undertaking per kilowatt installed	£50	—	£33
	Pence per unit sold		Pence per unit sold
Costs :—			
Generation	0·41	—	0·162
Distribution, rates, and taxes, etc.	0·25	—	0·104
Management	0·15	—	0·022
	0·81	—	0·288
Annual capital charges	0·685	—	0·252
	1·495	0·842d.	0·54

Correcting the 1904 figure to a 50 per cent load factor the estimated saving to-day through cheaper plant, larger plant, and other improvements, is 36 per cent. It will be said that a very marked improvement has been made on my figures of 1904. That is so, but it is not possible that there should be anything like the same margin on the 1914 figures, though improvements not at present even contemplated may still further slightly reduce the figure which I have ventured to put forward. The improvement, however, must be necessarily slight, since the lower the costs of production the less margin must there obviously be for any further reduction.

Such low costs of production can be obtained by stations of moderate size as well as by very large stations, provided a high load factor can be reached. The large station, however, has the advantage of using larger units of plant and lower capital costs, so long as these are not outweighed by increased costs of transmission.

In this country we are to a great extent dependent on coal for the maintenance of our industrial position. Coal is one of our great national assets, and it is lamentable to think how grossly it is wasted. It is not very comforting to engineers to think that only some 20 to 25 per cent of the energy stored in coal is usefully transformed into electrical energy in well-managed systems having an average yearly load factor of say 25 per cent and employing modern boilers and appliances and steam turbines. The greatest losses occur in the steam-raising plant of course, and in the heat rejected to condensers. Station engineers would do well to keep a regular log of the analysed losses and go further than merely checking the thermal values of coal purchased and the weight of coal per unit generated. It would pay in all but the smallest stations to have an assistant whose duties would wholly consist in noting the thermal values from the coal consumed right down to the remaining value per unit delivered to feeders, so as to improve the results and to minimize waste.

Manufacturers have awakened to the necessity of electrically equipping their works, whether mines or rolling mills, textile or grain mills, shipyards or engineering works, and factories of many other kinds. The removal of local steam and other plant in such factories and its replacement by motors driven from some public supply system is one great and important gain, and some waste of coal is thereby avoided.

A reduction in the number of open domestic fires would effect an enormous saving. In time this will follow, but meanwhile a prodigal waste of coal takes place, and the present generation are not yet good stewards of the natural riches committed to their care.

Capital Investment in Electrical Works.

As an indication of the development of electrical undertakings and companies in the British Empire, the following figures show a remarkable amount of capital invested. The sums given are not exactly correct, because it is difficult to differentiate some of the manufacturing and miscellaneous capital invested in the Empire from those registered British firms which have capital invested in foreign countries such as the Argentine, Chili, and China. Nevertheless, the amounts given are approximately correct :—

	£
310 Manufacturing companies	46,703,047
178 Miscellaneous companies	8,756,417
Telegraphs and telephones	37,249,088
269 Electrical supply companies	58,364,885
262 Municipalities	49,656,951
104 Tramway undertakings	56,012,466
	£256,742,854

This huge total does not even then include Government telegraphs and telephones, power companies, or the capital invested by railway companies in electrification, which would greatly increase this total. It is nevertheless a very large amount, and is an indication of the great importance which the electrical industry has attained. When one considers that in a period of 30 years over 250 million sterling has been invested in electrical undertakings of various kinds, none can deny that electricity has become indispensable to the service of mankind.

Trend of Improvements.

We are gradually arriving at definite and accepted methods. In power-station work there can be no question that 3-phase generation has such great advantages over any other system that it must be generally accepted as the system of the future. Turbo-alternators of the highest adaptable speed coupled to machines of simple design (by simple machines I mean one bar per slot) having the lowest

* J. F. C. Snell. Distribution of electrical energy. *Minutes of Proceedings of the Institution of Civil Engineers*, vol. 159, p. 143, 1904–5.

[illegible] adopted wherever possible.

Do not from this think that batteries will not also play an important part in electrical distribution systems. I believe they will often do so. They can of course be readily provided for in sub-stations through the medium of rotary transformers. Simplicity is, however, what we must aim at, the invariable result of which is economy.

In the [illegible] standardization [illegible] can be turned out in quantities, the articles are cheaper than when the stock order is small. Whether it be units of energy or motors, the curve of cost per unit or per motor will be hyperbolic. There are fixed charges and running charges in both, and the greater the quantity, within given limits in each case, the smaller the cost of each. Is this always realized?

Electrical science has rendered a great service to many other industries besides engineering—in teaching exactitude of measurements and in making more widely known the underlying principles of the cost of production. Some continental competitors have realized this, and by absorbing the fixed charges at home, have delivered machines and materials here at prices which have been based on the "running costs" only. In so doing, however, they have improved their own factory load factor and increased their prosperity. Our manufacturers have an opportunity now, and if they will turn out standard plant more boldly and in numbers, economies to suppliers and purchasers alike will result and increased output.

Steady progress is being made in our designs by the better utilization of raw materials. There is now very little superfluous iron, steel, or copper in our generators and motors. In our distributing systems I am not so sure that we have made the same progress. For instance, an appreciable waste takes place in most cities through the constant taking up and relaying of pavements by the gas, water, telephone, and electrical authorities, all of which work has to be paid for. Some co-ordination here is distinctly advisable. I refer particularly, however, to a more systematic design of extensions of the distributing systems themselves. It is true that a few chosen standard sizes of cables are now generally adopted in any given network; still it seems to me that unnecessary copper and lead are often laid down in a hurry, when a skilled consideration of plans prepared well in advance would generally result in economies, while affording at the same time a better pressure distribution and greater facilities for sectionalizing the system in emergencies.

If we turn to railway electrification we seem as yet no nearer a solution of the rival claims of the overhead high-pressure system and the third rail. The tendency in this country is certainly in favour of the latter, because the great railways are confining themselves to suburban traffic, for which the third rail has decided advantages. It would seem a long cry to main-line electrification in Britain, [illegible] the London and North-Western Railway, London, and then [illegible] Manchester district, each in turn electrifying their local [illegible] continuous electrification from London to Preston at any rate.

We have also to consider the equipment of lines in British Dominions and of British-owned foreign lines, where coal is generally so much dearer. In many of these cases, owing to the long distances to be traversed, it would seem necessary to adopt an overhead high-pressure system. There can be no doubt that the economic effect of suburban electrification in this country has been markedly successful, and has resulted in improved returns to those railways which have adopted it, and we can confidently expect that wherever commercially practicable further electrification will follow.

I have touched lightly upon a variety of subjects in the course of this address: some of them, such as bulk supply, domestic supply, or railway electrification, would really require treatises to themselves in order to be effectively dealt with. My remarks, however, may suffice to show that though electricity is no longer in its childhood, but has grown to a vigorous manhood and exercises an ever-widening influence, there is still much to do, and we are a long way from the end of the road. That should be an encouragement to us all.

Many of the improved conditions of living are directly due to the use of electricity. Communication between peoples is really easier than our grandfathers ever enjoyed or even dreamt of; travel is safer; the pleasures of life are greatly increased; the great medical profession is assisted by electrical discoveries, and human suffering has thus been alleviated: even the conquest of the air has only been made possible through the assistance of electricity. Some of the great natural sources of power which otherwise were wasted have been effectively used, though much remains to be done in this direction. There is much left to unravel, and the assistance which electricity has given to the chemist may, and probably will, yet enable mankind to make further great discoveries and lift the veil still higher, revealing to us more and more of those marvellous circumstances with which we are surrounded.

This is largely a commercial age, but while not neglecting the obviously necessary attention which we must give to commercial and industrial interests, let us not underestimate the great privileges that we electrical engineers especially enjoy of understanding more clearly and of effectively using the great natural forces, in the utilization of which electricity has been such a powerful agent; or of comprehending with clearer vision natural laws and the Creative design that underlies and controls them all.

May this Institution always encourage scientific research, assist in spreading the blessings of education, and influence greatly the upward progress and development of mankind.

EXPERIMENTS ON THE HEATING OF SCREW-SOCKET LAMPHOLDERS.*

By CLIFFORD C. PATERSON, Member.

(Paper received 10 June, 1914.)

OBJECT AND GENERAL CONCLUSIONS OF REPORT.

The tests described in this report have been made with a view to the investigation of the temperature rise in screw-socket lampholders of different types when used—

(a) with radiators,

(b) with lighting fittings.

The maximum number of watts that may be safely transmitted by a screw-socket lampholder depends on different considerations from those which prevail in the bayonet holder. The limiting factor in the bayonet socket is the gradual weakening of the plunger springs which takes place when the temperature reaches too high a value. The screw socket has no such springs, but connection is made to the lamp-cap terminals by what is equivalent to a clamped contact as the lamp is screwed into place. A rise of temperature such as the lamp itself is able to withstand has not been found in any way to affect the soundness of the contacts in the experiments made, and there is no reason to suppose that any other result would be obtained under the conditions met with in practice, provided mechanical agencies such as vibration do not cause any unscrewing of the lamps themselves in their sockets.

In determining the maximum rating of a lamp socket, however, there is the important factor of the heat that is conducted along the cable that supplies the current to the lamp. This factor applies mainly to sockets used for lighting, since the leading-in wires to radiator sockets are not generally, and should never be, insulated with rubber, but with some heat-resisting covering. Where screw-socket lampholders are used for lighting fittings, flexible cable to the socket is usually led either through a cord grip or through a length of metal tube on to which the lamp socket is screwed. Where a cord grip fitting is used, the lamp is generally small and in this country bayonet holders are almost exclusively employed. The larger lamps, however, ranging from 300 to 1,000 watts, are used with screw sockets of either the normal or the larger size, and the positive and negative cables to these sockets are generally led together through a tube. Thus there is no insulation to be relied on except that of the cables themselves, and it becomes a matter of real importance in the design and rating of such sockets to know to what temperatures such insulation is subject under working conditions.

Measurements of the contact resistances of the various sockets have confirmed the previous tests † and show that the actual I^2R losses due to current passing through the contacts are negligible, and that all the heating is caused by conduction and radiation from the lamp itself. The wattage of the lamp is therefore the main factor to be considered. A subsidiary influence is the size and shape of the lamp itself, which may somewhat affect the heating of the socket. As, however, most commercial lamps of the same rating will be found to be very similar in shape and dimensions, this factor, always small, is not of importance.

It may be stated at this point that the general conclusions arrived at as the result of the experiments described in this report are (a) that as far as temperature rise is concerned ordinary screw-socket holders may be used for radiator elements up to at least 500 watts each (the maximum size of heater element at present on the market); (b) the screw contact is also satisfactory, as at present used, for lamps rated up to at least 1,000 watts, but in the present designs the clamping contacts for the incoming leads become too hot to allow rubber-insulated cables to be brought direct into the sockets without risk of serious deterioration of the rubber.

RADIATOR TESTS.

*Apparatus used.**—Two radiators were used for the measurements, and are here denoted by No. 1 and No. 2.

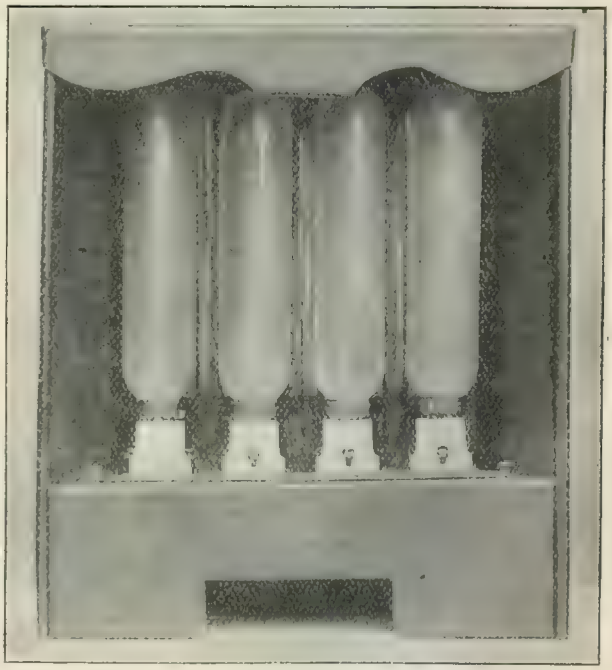


FIG. 1.

Various types of sockets were tested, and both radiators and sockets are illustrated in Figs. 1 and 4. The

* Paper based on a report (dated November, 1912) to the Lampholder Panel of the Engineering Standards Committee upon experiments carried out at their request at the National Physical Laboratory.

† A report to the Committee in June, 1910

* The radiators used in the tests were to some extent of an experimental character, and the results given here must not be used to compare the relative merits of the two makes. They were specially constructed and given by two firms for the purposes of the experiments.

[illegible] shown in Fig. [illegible] the greatest heating of the [illegible] and although [illegible] of [illegible] the temperature [illegible]

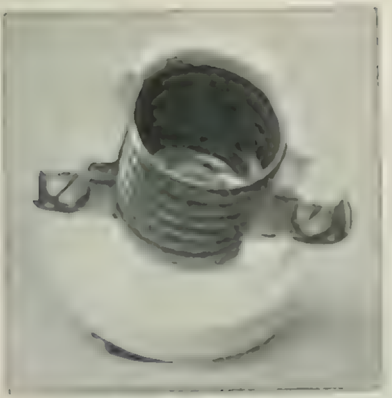


Fig. 2.—Type A.

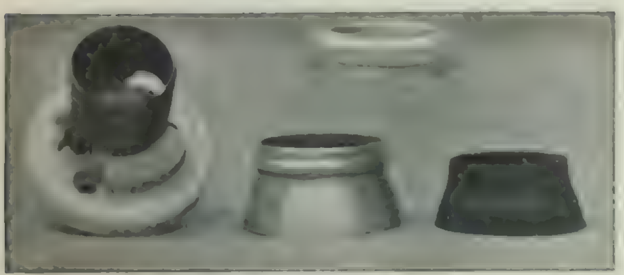


Fig. 3.—Type B.

Fig. 4.

exceed those given, the experiments show that such differences are not likely to be serious. Of the upper ratings only those heating elements taking 250 and 500 watts were obtainable. The 250-watt heaters caused a relatively slight rise of temperature and there was no

difference between [illegible] and [illegible] in the same ceiling.

[illegible]

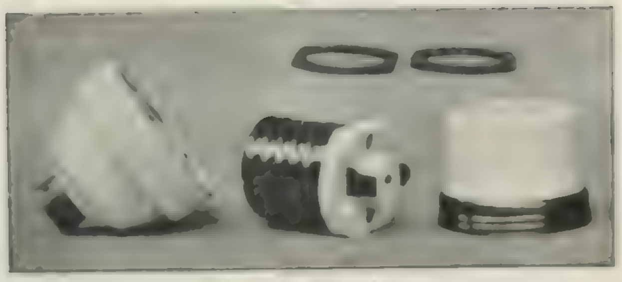


Fig. 5.—Type C.

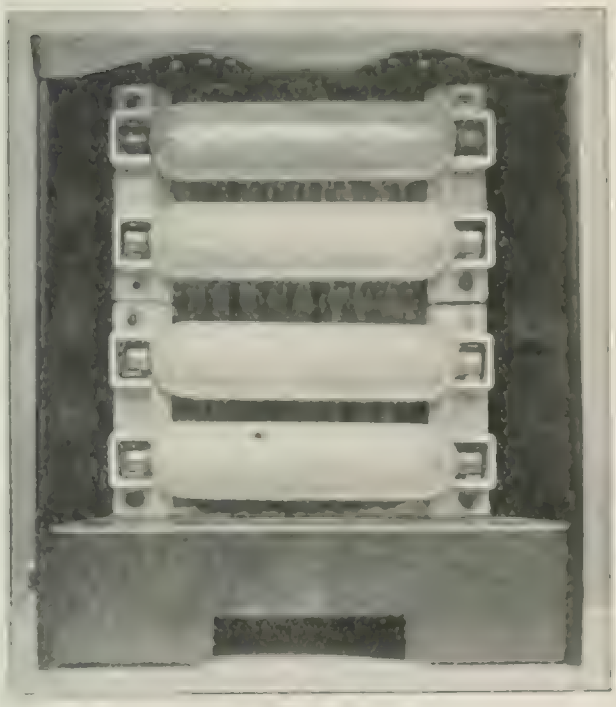


Fig. 6.

Fig. 7.—Type D.

measurements were made with [illegible] elements—representing the most exacting conditions [illegible] with respect to the current to be carried and the number of watts to be dissipated.

Radiator No. 1.—It will be seen in Fig. 1 that the radiator is of the small 4-element type painted dead black. It was arranged so that lamps could be fixed either upright or pendant. Two thermo-junctions were run into each socket. One was fixed to each of the two contacts to which the supply leads were clamped, and when necessary a third junction was brought to a point inside the socket which would give a measure of its general internal temperature. After the heater elements were switched on, temperature measurements were made at regular time intervals until a steady value was attained. This generally required from one to two hours.

Table 1 gives the final temperatures reached in type A and type B sockets when used in No. 1 radiator. The sockets are shown in detail in Figs. 2 and 3, and their general construction can be seen from these illustrations. The chief point to note is that socket A has external, and B socket internal, contact clamps for the incoming leads.

The circumstance that the 500-watt 100-volt heaters showed a somewhat higher temperature than the 240-volt heaters of the same rating is accounted for by the fact that the 100-volt heaters took a little more, and the 240-volt heaters a little less, than their rated watts.

The temperature rise when the 500-watt lamps are arranged pendant is considerable (150° C.); but as the sockets consist of only porcelain and metal, and as it is presumed that the leads away from the sockets are insulated with beads, there appears to be no special harm in this temperature as far as the socket is concerned.

Radiator No. 2.—This radiator (illustrated in Fig. 4) is of a larger type and is made of burnished copper. It was tested with type B socket (Fig. 3) and also with a large type of screw socket, C (Fig. 5), which was supplied with it, the heater elements used being the 500-watt type.

Table 2 gives the results obtained.

It will be seen that the temperature rise in type B socket was rather less with this radiator than with the smaller No. 1 type, particularly that of the centre contact, which would be somewhat affected by the cooler case of the large No. 2 radiator. An interesting point is the higher temperature reached by type C socket, which is one of the extra large Goliath type with a screw $1\frac{1}{2}$ in. in diameter.

TABLE 1.

Radiator No. 1.

	Temperature rise above air					
	Heater elements upright			Heater elements pendant		
	Contact for lamp centre	Contact for screw socket	Centre of socket	Contact for lamp centre	Contact for screw socket	Centre of socket
	deg. C.	deg. C.	deg. C.	deg. C.	deg. C.	deg. C.
Four 250-watt 240-volt heaters (total watts = 968)						
Type A socket No. 1	42	37	44	76	73	76
" " 2	50	42	48	78	76	79
" " 3	48	41	50	76	72	77
" " 4	34	42	48	68	76	84
Average	43·5	40·5	47·5	74·5	74	79
Four 500-watt 240-volt heaters (total watts = 1,968)						
Type A socket No. 1	83	67	90	143	136	147
" " 2	94	87	90	158	153	154
" " 3	90	79	102	150	144	162
" " 4	64	79	94	123	137	153
Average	83	77	94	143·5	145	154
Four 500-watt 100-volt heaters (total watts = 2,030)						
Type A socket No. 1	89	72	94			
" " 2	106	91	106			
" " 3	98	88	110			
" " 4	70	86	103			
Average	91	84	103			
Four 500-watt 100-volt heaters (total watts = 2,030)						
Type B socket No. 1	80	76				
" " 2	86	89				
" " 3	86	92				
" " 4	75	81				
Average	82	84·5				

TABLE 2.

Radiator No. [illegible]

	[illegible]	
	[illegible]	[illegible]
Four [illegible]-watt [illegible] heaters (total watts [illegible])		
Type B socket No. 1 ...	[illegible]	[illegible]
" " " 2 ...	[illegible]	[illegible]
" " " 3 ...	[illegible]	[illegible]
" " " 4 ...	[illegible]	[illegible]
Average	[illegible]	[illegible]
Four [illegible]-watt [illegible] heaters (total watts [illegible])		
Type C socket No. 1 ...	[illegible]	[illegible]
" " " 2 ...	[illegible]	[illegible]
" " " 3 ...	102	[illegible]
" " " 4 ...	[illegible]	[illegible]
Average ...	[illegible]	[illegible]

[illegible] was not available for comparative tests and it is impossible to say whether any of this temperature rise is due to the particular heaters which were mounted with the large caps. As the four heaters gave approximately uniform results it would not be expected that the difference could be attributed to this cause. The reason is possibly the easier path for conduction to the contacts given by the large cap, combined with the thick porcelain base of the socket acting to some extent as a heat insulator.

Another firm presented four heater units in which the screw cap was not in metallic contact with the base into which the glass was cemented, but was insulated from it by a vitrite ring. A comparative test, however, between these heaters and heaters mounted in the ordinary way, showed no difference in the temperature of the different parts of the sockets used with them.

Resistance of contacts in screw-socket holders.—At the same time as the temperature observations were made on type A socket (Fig. 2) given in Table 1, measurements were made of the contact resistances between the lamp-cap terminals and the contacts in the sockets, with the object of ascertaining whether the number of watts lost at the contacts was appreciable and was sufficient to generate any local heat which might lead to ultimate trouble.

Table 3 gives the average contact resistance of the four type A sockets when they had attained their final temperature in the tests described above.

It will be seen from this that the contact resistances in a screw-socket lampholder may be taken as about 0·0004 ohm. This with 5 amperes means about 1/10th of a watt; so that the question of the generation of heat at contacts may be left out of account. It also follows that for a given watt rating the particular current and volt rating of the heater is not a matter of concern, and that the number of watts only has to be considered.

TABLE 3.

Type A socket.

[illegible]	[illegible]	[illegible]	
		[illegible]	[illegible]
[illegible]	...	[illegible]	[illegible]
[illegible]	...	[illegible]	[illegible]
[illegible]	...	[illegible]	[illegible]

There is [illegible] variation in the [illegible] in different sockets, and the above figures may be regarded as representative.

Radiator No. 3.—One of the firms submitted a special horizontal radiator (Fig. 6) with four 250-watt heater elements, the contact clips being at either end. The final temperatures reached by the contact clips and the contact resistances of four clips were found to be as follows:—

TABLE 4.

	[illegible]	[illegible]	[illegible]
Heater No. 1 [illegible] ...	[illegible]	[illegible]	[illegible]
" " 2 ...	[illegible]	[illegible]	0·0001
" " 3 [illegible] ...	[illegible]	[illegible]	[illegible]
" " 4 [illegible]	[illegible]	[illegible]	[illegible]

Tests on Lamps in Lampholders.

The measurements in this section of the report have been made in order to find out the temperature conditions existing in screw-socket lampholders used with metal-filament lamps rated at from 300 to 1,000 watts.

The practice of different lamp makers varies somewhat as to the type of lamp cap which is fitted for the various ratings. Bayonet caps are always fitted up to 100 watts, and generally up to 200 watts. Ordinary Edison screw-holders are almost always used for 300 watts, and in some cases for 400 and 500 watts. All makers fit Goliath caps [illegible]

There is little doubt that the practice of confining bayonet sockets to lamps of 200 watts and under is sound. There are two main considerations, however, in choosing between the ordinary and the Goliath screw

* [illegible]

caps for other ratings. One is the temperature rise of the incoming cable, and the other is the suitability of the clamping terminals in the sockets for properly "looping in" a supply main of sufficient size. The results show that the temperature rise in the small and the large screw

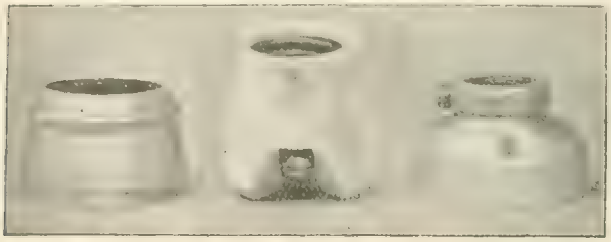


FIG. 8.—Type E.

FIG. 9.—Type F.

FIG. 10.—Type G.

FIG. 11.—Type J.

sockets as at present made is about the same for the same watt rating. If the small socket is made mechanically strong enough therefore, and the lamps are screwed up tight into position, there would be no serious objection to the use of small sockets up to 600 watts provided the incoming leads could be properly accommodated. This would not be easily done with such a socket as type D (Fig. 7), but the "tube" type, E (Fig. 8), leaves ample room, although the clamping screws themselves are not perhaps of the most efficient type. The general use of Goliath sockets for the higher-power lamps may be justified on the ground of general robustness; but from electrical and heating considerations only, the smaller size would probably suffice for all except the largest sizes in the neighbourhood of lamps taking 1,000 watts and upwards—and a well and strongly designed Edison

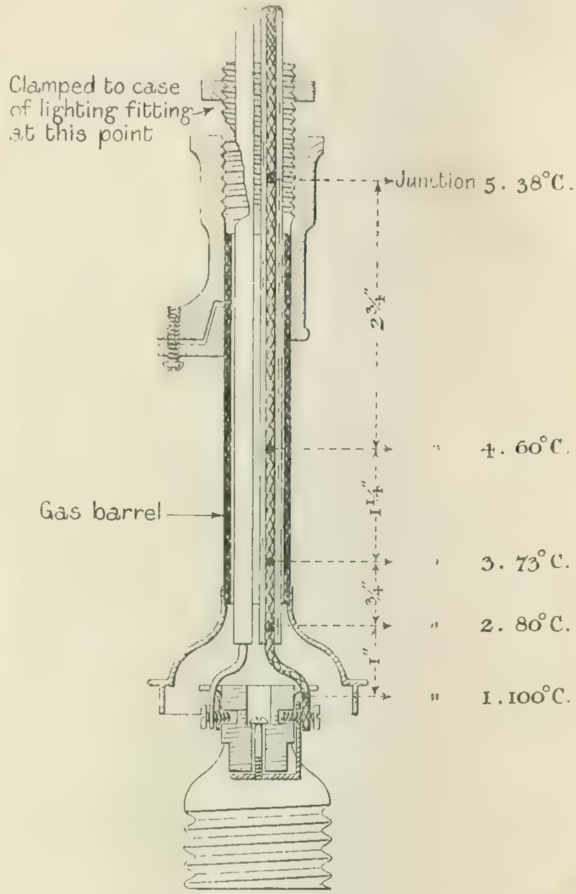


FIG. 12.

screw socket would probably prove as efficient as the present heavier Goliath type up to 500 and 600 watts. Further, there appears to be nothing in the glass-work of the lamp mounting to prevent the ordinary Edison screw socket from being used for the 600-watt ratings.

The object of suggesting that small screw sockets might have to be used for 600 watts is that as at present constructed the Goliath sockets used with 1,000-watt lamps have a temperature rise above air of upwards of 100°C. in the neighbourhood of the rubber insulation. Some change may therefore have to be made in their design, and as such alteration may necessitate an increase in the length of the socket there may be real advantages in being able to dispense with the Goliath type for the 600-watt rating. This assumes of course that the temperatures at present reached with 600-watt lamps are not regarded as excessive.

Table 5.

[illegible]	[illegible]	[illegible]	[illegible]		
			[illegible]	[illegible]	[illegible]
Type D	[illegible]	[illegible]	[illegible]	[illegible]	41
Ordinary Edison screw	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Type E (tube)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Ordinary Edison screw	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table 6.

[illegible]	[illegible]	[illegible]	[illegible]		
			[illegible]	[illegible]	[illegible]
Type D	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Ordinary Edison screw	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Type E (tube)	[illegible]	375	[illegible]	[illegible]	49
Ordinary Edison screw	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table 7.

[illegible]	[illegible]	[illegible]	[illegible]		
			[illegible]	[illegible]	[illegible]
Type D, Ordinary	100 v. 600 w.	[illegible]	[illegible]	[illegible]	[illegible]
Edison screw	240 v./600 w.	[illegible]			
Type E (tube)	100 v. 600 w.	[illegible]	[illegible]	[illegible]	[illegible]
Ordinary Edison screw	[illegible]	Socket showed excessive heating, probably due to bad lamp vacuum			
Type F, Goliath	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Edison screw	240 v./600 w.	[illegible]	[illegible]	[illegible]	[illegible]
Type G, Goliath	[illegible]	597	[illegible]	[illegible]	[illegible]
Edison screw	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Type C, Goliath	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Edison screw	[illegible]	[illegible]	57	[illegible]	[illegible]
Type J, Goliath	[illegible]	[illegible]	53	[illegible]	[illegible]
Edison screw	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table 8.

[illegible]	[illegible]	[illegible]	[illegible]		
			[illegible]	[illegible]	[illegible]
Type F, Goliath	100 v. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Edison screw	240 v./1000 w.	[illegible]	[illegible]	[illegible]	[illegible]
Type G, Goliath	100 v. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Edison screw	240 v. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Type C, Goliath	100 v. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Edison screw	240 v./1000 w.	[illegible]	[illegible]	[illegible]	[illegible]
Type J, Goliath	100 v. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Edison screw	240 v. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]

The arrangement for the tests described below only extended to the use of one type of lantern—that illustrated in Fig. 13. This is the usual type sold by one firm for

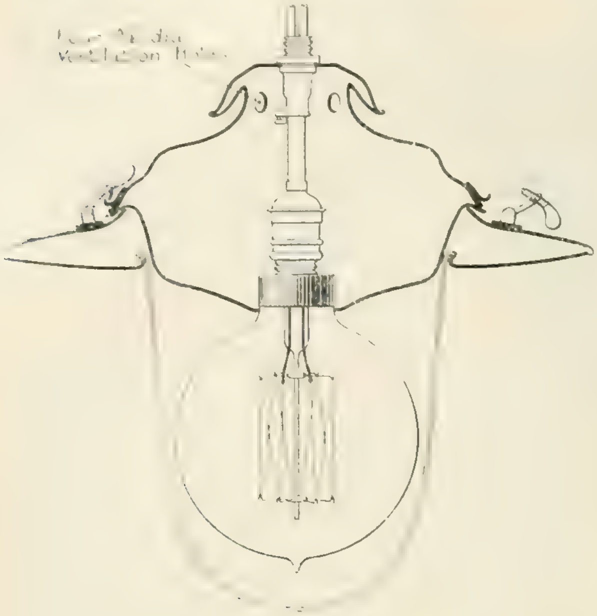


FIG. 13.

outside lighting with metal-filament lamps. It is impossible to say to what extent other types would show still higher temperatures, but there is little doubt that many

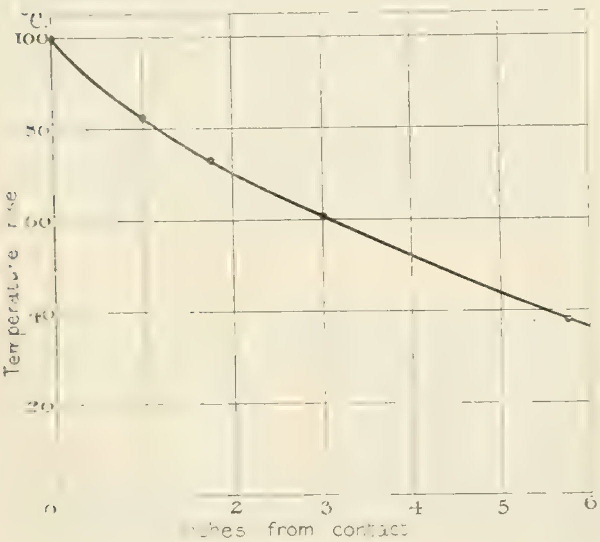


FIG. 14.

lighting fittings are installed at the present time in which the rubber insulation of the leads is subject to temperatures exceeding 120° C.

Measurements of the temperature gradient along the cable from a lamp socket are given and discussed later.

Sockets and lamps used in experiments.—Six types of sockets were used in the experiments—two of the ordinary Edison screw pattern and four of the Goliath pattern. These are illustrated in detail in Figs. 5, 7, 8, 9, 10, and 11.

The lamps were of the ordinary clear-glass round-bulb type, the ratings being 300, 400, 600, and 1,000 watts. Both high-voltage and low-voltage lamps were obtained in some of these ratings; in which case both types were tested, but with practically identical results.

Procedure of test.—The procedure of test was very similar to that described for the radiators. Thermo-junction wires were led in with the leads supplying current to the sockets, and were fixed to the cable where it was clamped to the terminals. An additional thermo-junction was taken farther inside the socket to give an indication of the temperature of the space immediately surrounding the contacts. These temperatures are scheduled in Tables 5, 6, 7, and 8.

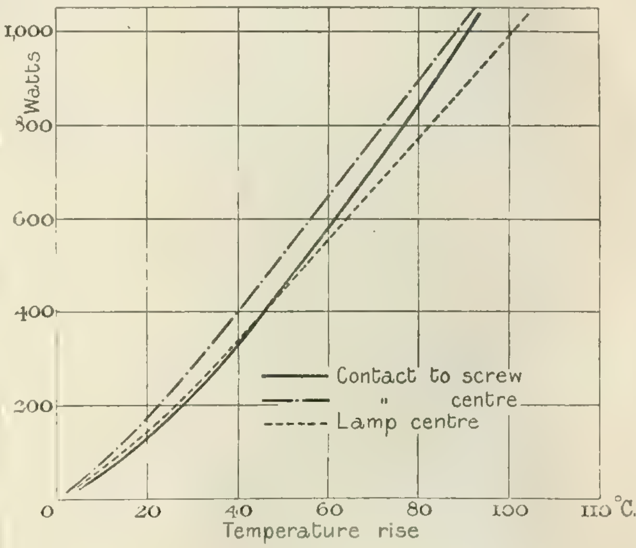


FIG. 15.

The temperature reached will depend within a few degrees on the shape of the lamp. For instance, a 1,000-watt lamp run at 600 watts will give a slightly hotter socket than a nominal 600-watt lamp run at 600 watts.

The investigation of such points, however, is not of any value in connection with this report, since such differences are likely to be quite masked by factors resulting from variations in the design of fittings.

Results.—The results of tests with 200-watt lamps are given in Table 5, with 400-watt lamps in Table 6, with 600-watt lamps in Table 7, and with 1,000-watt lamps in Table 8.

The results given in Tables 5 to 8 are summarized in Fig. 15, in which the mean temperature rise of all the sockets is plotted against the number of watts transmitted. This gives a general indication of the temperatures likely to be reached for any given lamp rating. As a general rule it will be seen that the number of watts, divided by 10, gives in degrees Centigrade the approximate temperature rise of the socket above the air.

Heat conducted in the cable supplying the lamp.—The

[illegible]

TEMPERATURE RISE IN TWIN FLEXIBLE WIRES.*

By S. W. MELSOM, Associate Member, and H. C. BOOTH.

[illegible]

This paper deals with the temperature rise in flexible [illegible] connection to electrical heating apparatus.

[illegible] TO THE CURRENT PASSING THROUGH THEM.

In accordance with the request of the Committee, tests were made in order to determine the temperature rise with current of twin flexible wires with the various types of [illegible].

The wires tested, which were supplied [illegible] the Committee by the India Rubber, Gutta Percha, and Telegraph Works Company, Ltd., and Messrs. British Insulated and Helsby Cables, Ltd., were as follows :—

Twisted flexible wires.—Each conductor was insulated with cotton and pure (or vulcanized) rubber, and then braided in cotton or silk. The twin flexible wire consisted of two of these braided conductors twisted up together to form a double cord. The coverings and insulation respectively were :—

Silk covered, with both pure and vulcanized rubber insulation ; cotton covered, with both pure and vulcanized rubber insulation.

Each type of covering and insulation was supplied with the following sizes of conductor : Equivalent in S.W.G. to Nos. 1/22, 1/20, 1/18, 1/16, and 1/14.

[illegible] with cotton and vulcanized rubber. Two conductors laid up together were filled in with cotton and braided over with silk to form a circular cord. The equivalent sizes of the conductors were 1/22, 1/20, 1/18, 1/16 S.W.G.

"*Workshop*" *flexible wires.*—Each conductor was insulated with cotton and vulcanized rubber. Two conductors laid up together were filled in with cotton, braided over with coarse cotton to form a circular cord, and covered with preservative compound. The equivalent sizes of the [illegible] S.W.G.

[illegible] cotton and vulcanized rubber. Two conductors laid up together were filled in and braided over with hemp to form a circular cord and covered with preservative compound. The equivalent sizes of the conductors were 1/20, 1/16, 1/12 S.W.G.

[illegible] conductor in the same manner as in the former tests on insulated cables.

Preliminary observations were taken with one of the flexible wires laid along the floor and then suspended in the air. The final temperature rise was practically identical for both conditions, the only difference being that when laid along the floor the wire took a slightly longer time to attain to its maximum temperature. All the results here given are therefore for flexible wires suspended horizontally in air.

The preliminary observations showed some discrep- [illegible] muslin of open mesh which did not prevent free circulation with the outside air but was sufficient to exclude stray air draughts.

Resistance of conductors.—The conductor of each of the flexible wires used was tested for resistance. The values obtained varied from the standard resistance by from [illegible] generally higher than the standard value. The results given in the curves have been corrected for these divergences.

[illegible] show the connection between the cross-sectional area and the current and current density respectively that corre- [illegible] type of cable to represent the connection between current and temperature rise over a range of [illegible]

[illegible]

* [illegible]

and that the vulcanized rubber insulation, probably owing to its greater thickness, tends to cool the wire more than the pure rubber covering.

(b) The Temperature Rise in Flexible Wires used for Pendant Lamps.

According to the Institution Wiring Rules, par. 52, sections (a) and (b), flexible wires may be used under two distinct conditions. Under section (b), "For sub-circuits, etc.," it may probably be safely assumed that any heating to which the flexible wires are subject will be due to the current passing through them. Under section (a), "For pendant and portable appliances, etc.," the heating from the lamp or other appliance to which the flexible may be connected may, however, be considerable. It occurred to the authors, in view of these different conditions, that some experiments with the object of ascertaining approximately the extent of the heating from incandescent lamps might be of use to the Committee in determining the safe maximum currents for flexible wires when used under such conditions.

A twin flexible wire of a size equivalent to 1/20 S.W.G. was taken for the purpose of the tests, and was fitted to a lampholder and ceiling-rose in the ordinary way. The temperature of the wire was measured by means of minute thermo-junctions placed in the following positions: A, at the lampholder contacts; B, at the cord grip, and C, D, and E, let into the wire at points at various distances from the lamp as shown in Fig. 3. Lamps of various candle-power, and with both metal and carbon filaments, were

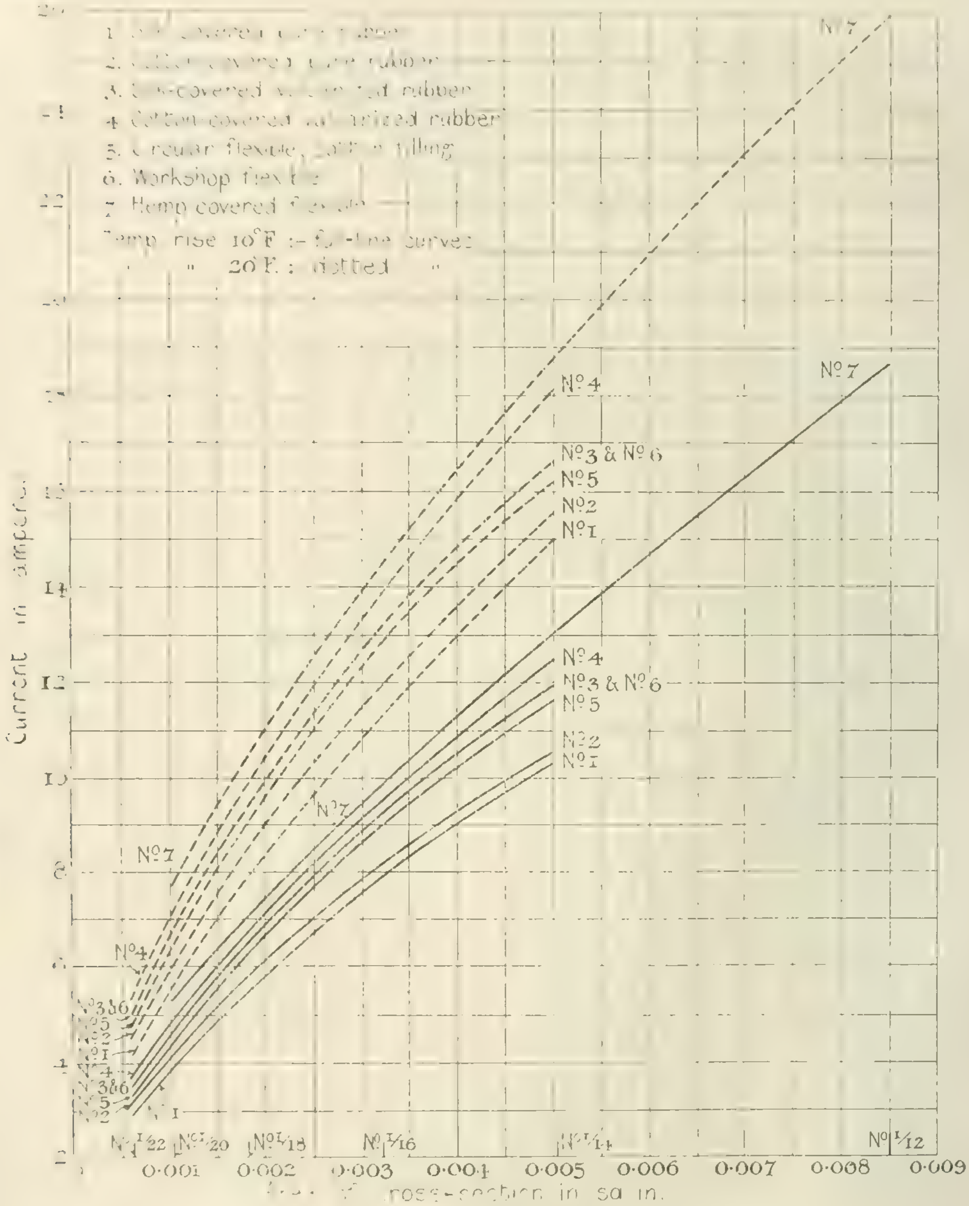


FIG. 1.

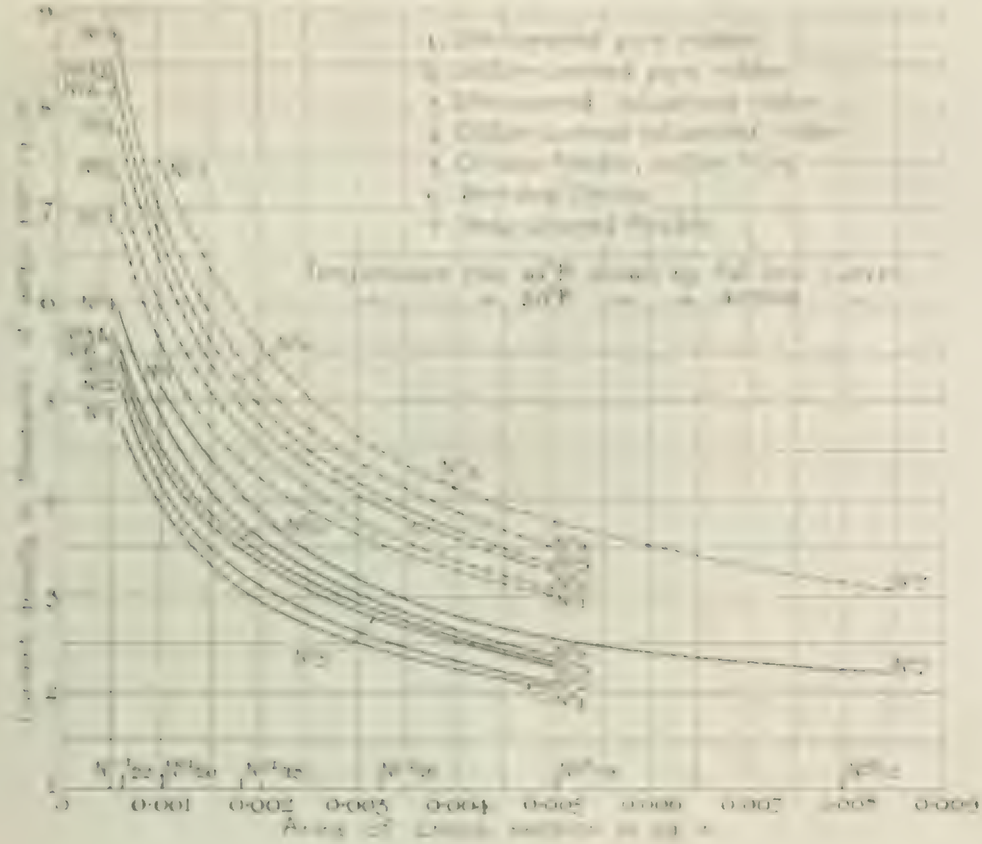
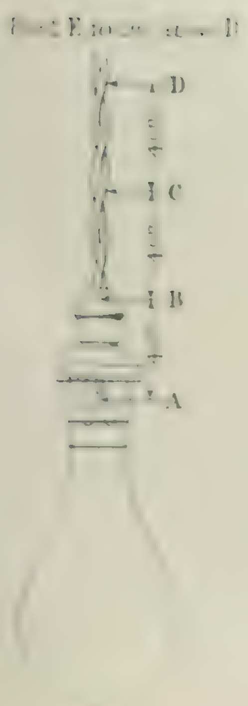
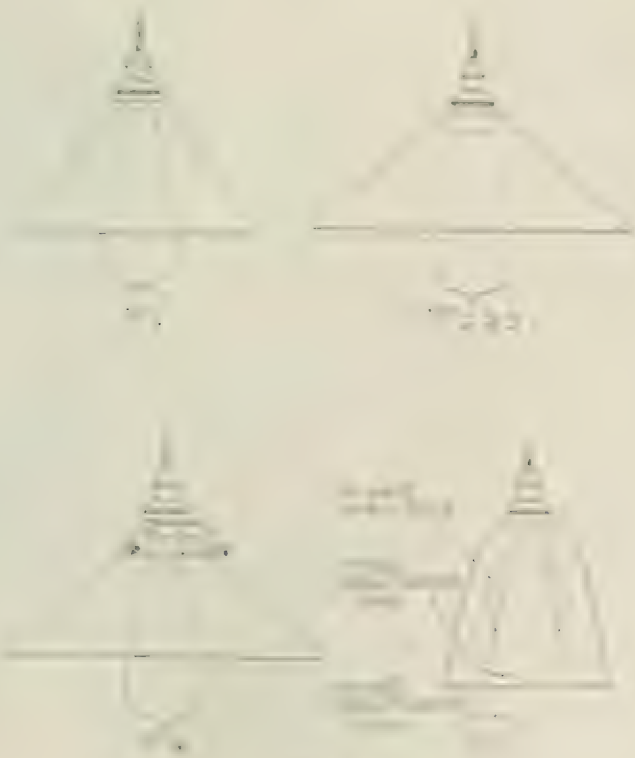


FIG. 2.





tested with various shades representing types in common use. The shades which are illustrated in Figs. 4, 5, and 6, were as follows:—

1. Small green and white opal glass.
2. White opal glass.
3. Enamelled metal.
4. White opal glass with gallery.
5. Holophane glass.
6. Iced glass.
7. Long, opal glass.
8. Short, opal glass.
9. Clear moulded enclosed glass shade with gallery.
10. Bead shade with gallery.
12. A special Holophane shade with gallery.

Shade No. 11 in Fig. 6 is No. 4, Fig. 4, used with a 100-watt metal-filament lamp.

The temperature rise observed at the various points on the flexible wire with the various lamps and shades was:—

20-watt metal-filament lamp. Temperature rise in degrees C.

Shade No.	A	B	C	D	E
5	20	14	7	4	1

32-watt metal-filament lamp. Temperature rise in degrees C.

Shade No.	A	B	C	D	E
5	16	11	5	3	1

55-watt metal-filament lamp. Temperature rise in degrees C.

Shade No.	A	B	C	D	E
1	33	24	15	9	3
2	22	14	5	2	1
3	24	16	8	3	1·5
4	17	10	5	1·5	0·2
5	32	23	13	5	2
6	22	13	5	1·4	0·5
7	38	20	12	7	2
8	20	16	4	2	
9	36	24	14	10	3·3
10	30	20	10	7	3·3
3-light bracket	18	12	5	—	—
Without shade	21	15	8	5	1

56-watt carbon lamp. Temperature rise in degrees C.

Shade No.	A	B	C	D	E
4	35	23	13	6	3
5	59	42	14	6	5
6	47	24	12	5	1
Without shade	39	26	24	6	2

100-watt carbon lamp. Temperature rise in degrees C.

Shade No.	A	B	C	D	E
5	95	65	42	26	10
6	67	41	16	8	—
Without shade	64	42	26	—	—

100-watt metal-filament lamp. Temperature rise in degrees C.

Shade No.	A	B	C	D	E
11	21	14	6	4	1
12	41	26	[illegible]	4	1
Without shade	26	18	10	9	3

This temperature rise is over and above any heating in the flexible wire itself due to the current flowing through it.

Thus, taking the quite ordinary combination of a 55-watt metal-filament lamp with shade No. 5 or a 56-watt 16-c.p. carbon lamp with shade No. 6, the temperature rise at point B, *i.e.* at the cord grip, is 24° C. (43° F.), or about twice the temperature rise allowed by the Wiring Rules for rubber insulation. With lamps of higher candle-power the rise is considerably greater.

The use of the gallery as in shade No. 4 (Fig. 4) keeps the lampholder and flexible wire much cooler than with shade No. 2, which is similar in size and material but which is closed at the top. This is owing to the provision for allowing the heated air to escape from the top of the shade and to the effect of the metal-work in promoting the dissipation of heat, as will be seen from the Table.

The temperature rise with shades Nos. 1, 5, 7, and 9, all of which are somewhat similar as regards size and shape, is nearly the same. In the beaded shade, No. 10, it is slightly less.

The difference between the results obtained with the 55-watt metal-filament lamp and the 56-watt carbon lamp when used with similar shades is no doubt due to a great extent to the bulb of the metal-filament lamp being longer, so that the shade does not so completely enclose it.

The results obtained were in a measure confirmed by an examination of a number of silk-covered twin flexible wires that had been in use during the past ten years in the lighting installation of the Laboratory. Near the lampholder the pure-rubber insulation had almost disappeared and the silk covering was very weak, but in the parts of the flexible near the ceiling-rose the silk was in good condition and the only sign of deterioration was that the rubber broke rather easily on stretching.

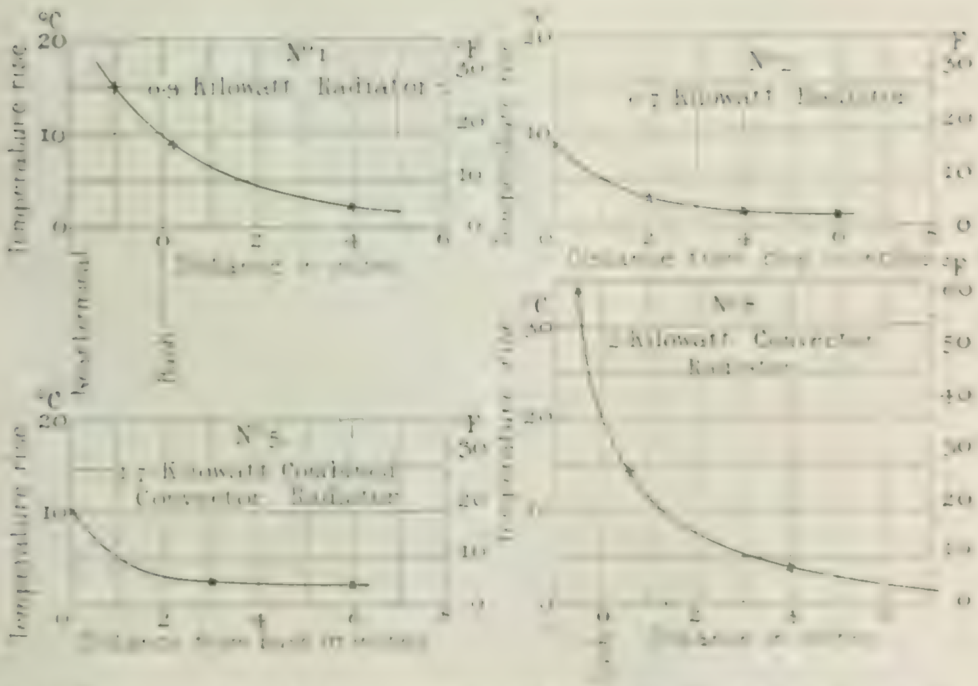
(c) THE TEMPERATURE RISE IN THE FLEXIBLE LEADS USED FOR CONNECTIONS TO ELECTRICAL HEATING APPARATUS.

The apparatus used for these tests were lent by the various makers who were approached by the Wiring Rules Committee. The types were selected from the ordinary stock as fairly covering the range of electric heating and cooking apparatus in general use and as representing the various methods adopted of connecting the flexible leads to the apparatus.

Heating apparatus.—Fourteen heaters in all, supplied by five different makers, were examined. For the purposes of this report these have been classified into four types, namely—

(1) Radiators in which the heating elements consist entirely of lamps;
(2) Combined convector radiators in which the heating element consists both of lamps and wire coils, the latter running at a temperature less than red heat;
(3) Convector radiators in which the heating elements are wire spirals enclosed by silica or other fire-proof containers and running at red heat;
(4) Convector heaters in which the heating element consists entirely of wire coils or resistance strip wound on some such material as uralite, porcelain, or mica, and running at a temperature less than red heat.

Method of connection of the flexible leads.—In all cases the flexible wires were run to the bottom of the apparatus.


°C
Temperature rise
N°1
0·9 Kilowatt Radiator
°F
N°5
Kilowatt Convector Radiator

The various makers adopted widely different methods of connecting the wires to the heaters. These methods might be classed as follows:—

(*a*) The flexible wires are passed into the bottom of the radiator case through a bushed hole or holes, the wires being left of such length inside that it is possible for them to touch each other or the radiator case.

Kettles.—Two kettles were examined. In each case the connection was made by means of split-pin plugs and socket connectors. The power required was 0·6 and 0·7 kilowatt respectively.

Flat irons.—Three flat irons were tested. The connections were made (1) by means of split pins fixed to the base of the iron and a socket connector; (2) by split pins

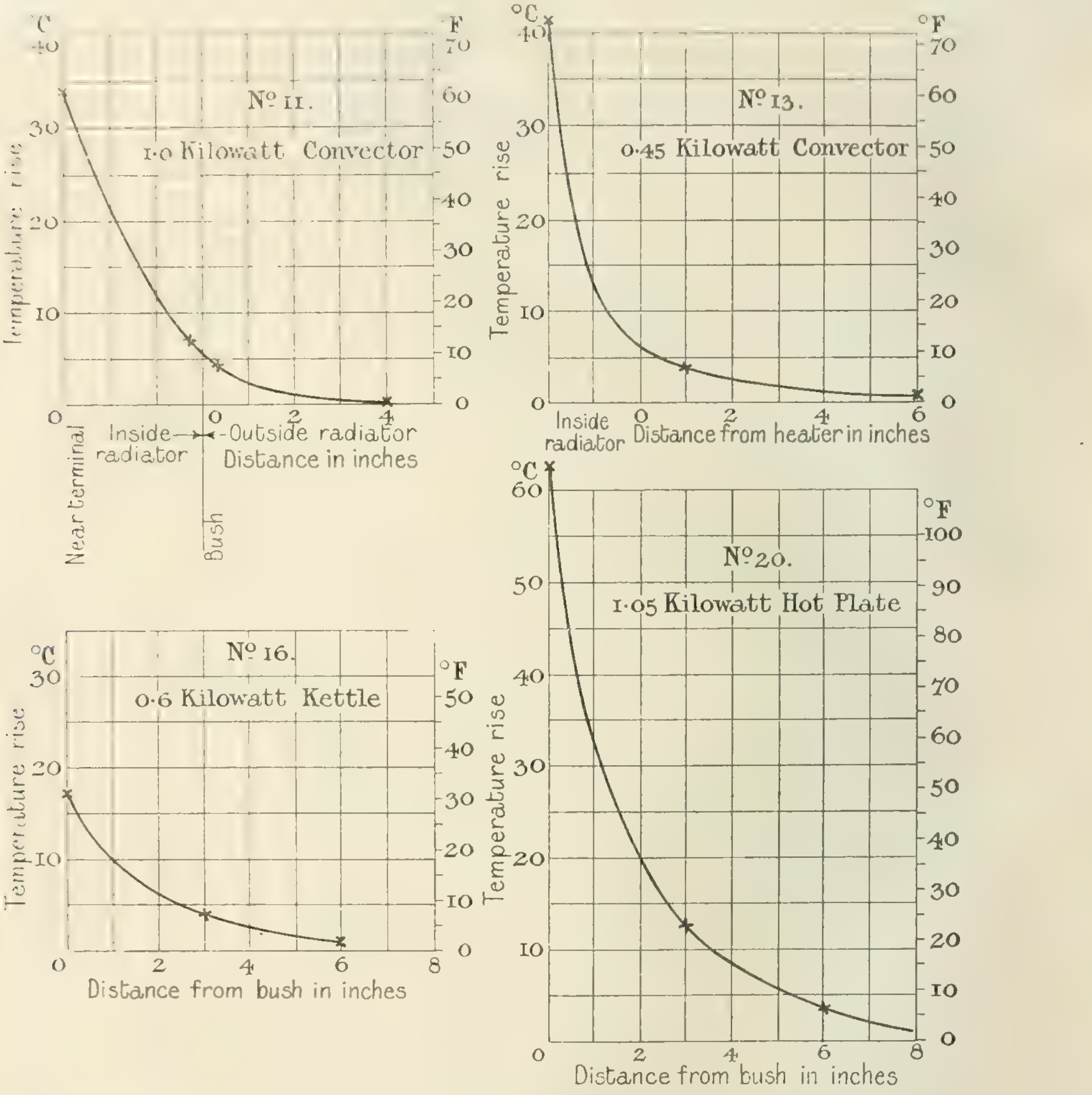


FIG. 8.—Temperature Rise in Leads and Connections of Heating Apparatus due to Heat Conduction.

(*b*) The wires are passed into the case as in (*a*) but the flexible leads are separated and each is taken direct to its proper terminal. The length of flexible wire inside the radiator case is short and the wires are not allowed to touch each other or the radiator case.

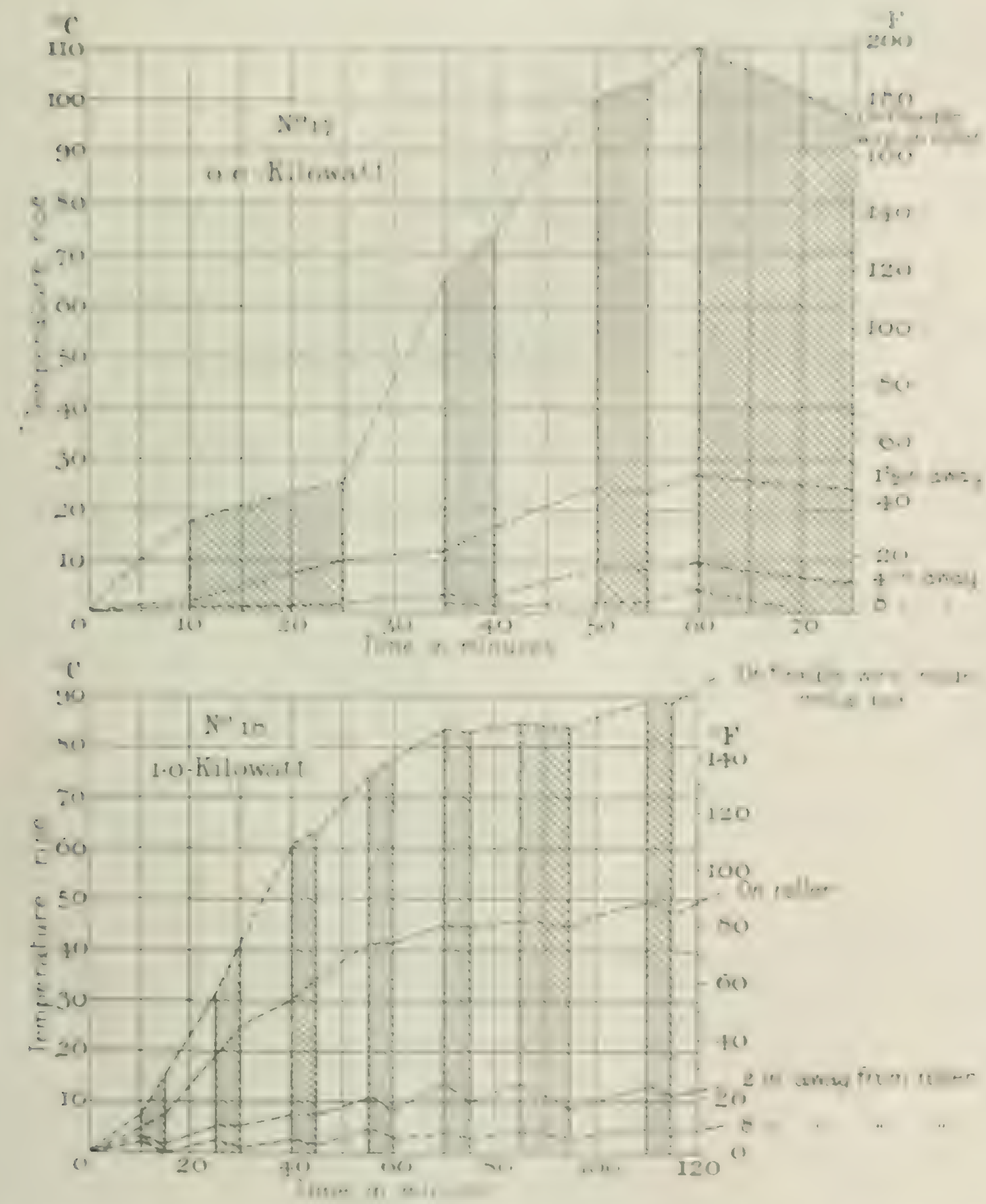
(*c*) The connections are made by means of plug sockets, pin plugs being fixed to and projecting from the outside of the radiator case.

Power.—The rating of the heaters varied from 0·25 to 2·5 kilowatts.

projecting from the base, the flexible wires being led through a long plug socket connector, the wires inside the connector being kept apart, and outside the connector being fastened round a cylinder of insulating material; and (3), by wires insulated with glass beads which were brought into a metal box on a level with the handle and were soldered inside the metal box to the flexible wires.

Cooking apparatus.—One oven, one hot-plate, and one griller were examined. The oven was heated by two

[illegible]



[illegible]

[illegible] In all cases the temperature rise was [illegible] the rubber insulation [illegible] the wires. In deciding where the junctions should be placed it was not considered [illegible] to fix them in any position other than that where the possible deterioration of the rubber insulation might result

Since the object of the investigation was to [illegible] the extent to which various parts of the flexible [illegible] [illegible] heating element, the temperature rise produced by the current carried by the leads is not included in the values shown, which represent the net effect ; the actual amount

of self-heating having been determined and allowed for in each case.

The conditions as regards the time of running of the apparatus were made as nearly as possible the same as in normal working. The radiators or heaters were run at full load until they had reached their maximum temperature. The kettles were filled with cold water, and after boiling were emptied and again filled with cold water.

In the case of cooking apparatus and flat irons the current was regulated in accordance with the instructions given by the makers, and the temperature was kept at the heating effect at different points on the connections are also given (see Figs. 7, 8, and 9), and illustrate the behaviour in this respect of different types of apparatus.

If we consider the whole of the apparatus examined, it will be seen that generally the smaller apparatus shows the greatest heating effects. This is especially the case with the flat irons and the hot-plates, which must necessarily be more restricted in size than radiators and which, generally speaking, are required to work at high temperatures.

TABLE I.

Heating Apparatus.—Temperature Rise (due to Heat Conduction) in Leads and Connections.

Type of apparatus	Reference No.	Nature of heating elements	Connection and introduction of leads	Power consumption	Temperature rise (net) at various points, in degrees Fahr. — Inside radiator	At bush or terminal	Outside bush, etc., distance away — 2 in.	4 in.	Time to attain maximum temperature
				kw.					
A. *Radiators.* Heating elements consist entirely of lamps	1	4 lamps	Through bush and separating inside	0·90	—	18°	8°	3·5	1½ hours
							(Distances are from plug)		
	2	4 lamps, horizontal	Through pin plugs	0·70	—	10° at plug	4·8°	2·5°	1 hour
							(Distances are from plug)		
	3	2 lamps, vertical	Through pin plugs	0·35	—	12·5° at plug	5·5	3·5	1½ hours
							(Distances are from outside)		
B. *Combined Convector Radiators.* Heating elements consist of lamps and wires, etc., running at less than red heat	4	Wire on porcelain tube and 2 lamps	Carried under the case to terminals inside the bottom	2·5	3	4·5	2·7	1·8	3 hours
							(Distances are from bush)		
	5	Resistance strip on mica and 2 lamps	Through separate porcelain bushes and thence direct to terminals	1·7	—	18	7	3·5	1 hour
C. *Convector Radiators.* Heating elements consist entirely of wire or strip enclosed in tube or container, and running at red heat	6	24 units; spirals in silica tubes	Through single bush to beaded wire	2·4	—	72	[illegible]	—	2 hours
	7	Hot bar	Through single bush to terminal block	2·0	61° (near bush)	—	14	7	2 hours
							(Distances are from switch)		
	8	6 units, horizontal	To outside switch	[illegible]·5	—	17° at switch	10	[illegible]	2 hours
							(Distances are from heater)		
	9	6 units, vertical	By flexible wire through bushed hole in base	0·65	50° (inside bush)	—	19	4	1 hour
D. *Convectors.* Heating elements consist of wires or strip running at less than red heat	10	Wire on asbestos strip	Through bush to terminals	1·3	38° at terminal inside	5·5° at bush	2	[illegible]	1 hour
	11	2 units; spirals on porcelain bars	Two pairs of flexible wire going through bush to porcelain block inside	1·0	61° at terminal inside	12·5° at bush	20	6	1½ hours
	12	4 asbestos strips wound with wire	Passing loosely through bush	0·[illegible]	25° inside heater	14·5° at bush	5·5	2·7	1 hour
							(Distances are from cover)		
	13	Wire wound on porcelain tube	Through bush into heater	0·45	74° inside cover	11° just outside cover	7	3·5	2½ hours
							(Distances are from plug)		
	14	Wire wound on porcelain tube	Double porcelain plug	0·25	21° in plug holder	7° inside flexible tube	3·5°	—	1 hour

approximately the same value as would be attained in practice. It will, however, be readily understood that where the heating is only required to be intermittent, or where the cooling that takes place must vary greatly in the different conditions of actual use, it is difficult to make any fair estimate of the amount. This qualification applies especially to the case of the flat irons, the heating curves for which are shown in Fig. 9.

Summary of results.—An analysis of the tests and results obtained is given in Tables 1 and 2. Curves showing

Assuming that the normal maximum air temperature in a room is 80° F. (30° C.), that the rise of temperature due to current flowing through the wires will not exceed 10° F. (5·6° C.), and that the safe temperature limit for rubber is 120 F. (49° C.), then the temperature rise due to conduction, etc., from the heating apparatus should not exceed 30° F. (17° C.).

With regard to the radiators, it will be seen from Table 1 that the temperature rise due to conduction from the apparatus on that portion of the flexible wire which is just

[illegible]

Table [illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]
Kettle	[illegible]	Porcelain double plug on projecting [illegible]	—	[illegible]	[illegible]	[illegible]	[illegible]
Kettle	[illegible]	Split-pin plug connector	[illegible]	[illegible] holder	[illegible]	—	[illegible]
[illegible]	[illegible]	Split-pin connector. Flexible led out [illegible]	[illegible]	[illegible]	[illegible]	[illegible] away	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible] metal box	[illegible] roller	[illegible] away	—
Flat iron	[illegible]	Porcelain double plug on projecting [illegible] flexible metal tube	[illegible]	[illegible] holder	[illegible]	[illegible]	[illegible]
[illegible]	20	Porcelain connector on to three pins [illegible]	[illegible]	[illegible] plug connector	[illegible]	—	[illegible]
Cooker [illegible]	[illegible]	[illegible] metallic tubing	0·8	31 where flexible leaves switch	[illegible]	—	After [illegible] full heat
[illegible]	22	Split-pin connector	1·0	80 inside [illegible]	[illegible] away from [illegible]	7 [illegible]	[illegible]

[illegible] Table 1 where the temperature [illegible] 72° F. (40° C.) at the single bush through which the flexible wires were taken. It seems clear that if the flexible leads were not taken inside the radiator case, or if each conductor was taken through a separate bushed [illegible] in most cases considerably in excess of 16·7° C. (30° F.), the highest values occurring with flat irons. This is most unfortunate, in view of the fact that in actual use the wire is subjected to far greater mechanical strain than with most of the other types of apparatus.

MANCHESTER LOCAL SECTION: CHAIRMAN'S ADDRESS.

By P. P. Wheelwright, Member.

(*Address delivered 3 November*, 1914.)

An Appeal to Members.

First of all let me take this, my first, opportunity to express my sincere thanks to the members for the honour that they have conferred upon me in electing me to be Chairman of this Local Section. Let me also assure them that it will be my earnest endeavour to extend the field of operation and the practical value of the Institution in this part of the country, emulating to the fullest extent the example of the gentlemen who have preceded me in office; and with the kind co-operation of members I shall endeavour to discharge the responsibilities of the chair worthily, and so uphold the position of the Manchester Local Section.

The problems that one has daily to solve and overcome are easy compared with the choice of a subject for an inaugural address. I do not propose to present a technical paper, for which a more suitable occasion would be an ordinary meeting where discussion is allowed. Here I may be permitted to generalize and briefly survey the work and scope of the electrical engineering industry. Particularly do I want to emphasize the business side, which has had a rapid development under varying and, of late years, exceptional conditions resulting from legislation, social conditions, and latterly international complications.

The session upon which we are now entering includes the reading of papers of considerable value and interest. I hope that members will avail themselves of the opportunities afforded to benefit mutually by attending the meetings regularly and by contributing to the discussions. With our numbers reduced owing to many of our members having offered their services to the country, it is more than ever necessary that we who remain at home should, even at personal sacrifice, carry on with redoubled energy the work of this Local Section.

From time to time papers will be read on subjects of value to manufacturers. I should therefore like to take this opportunity of inviting manufacturers to send representatives to these meetings to join in the discussions, thereby adding the commercial to the technical view, which latter is the more usual basis of debate. Opinions of commercial engineers are very valuable, since they are based upon actual experience; and I think the Institution would be wise in doing all in its power to cultivate the co-operation of these engineers.

The papers read before this Institution and before kindred Institutions in other countries become books of reference which are of inestimable value. I think that this material result of membership, together with the opportunities of meeting and conversing with other engineers in the various branches of this great industry, are powerful reasons why young engineers should join this Institution.

In the earlier stages of the profession the Institution was unable to draw its members from such a large body of engineers as at the present time, consequently it was then accepted as a purely technical society, and rightly so. Those days have passed, and what is now required is to widen the scope of the organization, make it as comprehensive as possible, and increase the advantages of membership. Not infrequently the remark is heard, "Membership only means the annual payment of a subscription and the receipt by post of a quantity of printed matter, acknowledged to be interesting and for its educational value acceptable, but nothing more." This is an exaggerated statement of the position, but, nevertheless, the fact that it is said proves there is something lacking.

I think that the Institution might with advantage widen its field of operation, make its presence more felt, and render its value to each individual very much greater. For instance, I hope that the time is not far distant when advertisements for positions of responsibility will state that applicants connected with the Institution will have preference. I do not wish this expression of opinion to be taken as a criticism, but rather as a suggestion of the position to which we should all wish the Institution to attain.

Status and Remuneration of Engineers.

The question of the status and remuneration of the electrical engineer is one that affects and interests most of us. Up to the present I consider that the inducements offered to young men to join the profession are insufficient. Analyse the qualities required of an engineer connected with an electric supply company or municipal department. Good general education, sound theoretical and technical instruction, and, lastly, thorough practical knowledge of the manufacture and maintenance of electrical and mechanical plant, are necessary; added to which the engineer in question must be keen, resourceful, broad and sound in judgment, and a good leader of men. Considering that these attainments are only achieved at considerable expense and after much time and experience, surely when such an engineer is given a position of trust the remuneration should be a little more in proportion to his responsibilities than what it is in many cases.

The work of the electrical engineer in the future is a great one, as the ever-increasing and economical application of electricity in this country has already shown; and only by persistent labour and by keeping up-to-date in all electrical methods can the status of the profession be maintained.

An engineer in a subordinate position has a hard and difficult climb before he wins what may be termed "the plums of the profession." In the meantime his salary is not much more than a living wage. Therefore I should

[illegible]

[illegible]

[illegible] is a task in which each one of us may take a part. That part means that whilst grave and troublous times continue [illegible] tapped.

Electrical engineering is passing through an extremely critical period, and in my opinion the blessings and benefits to come depend upon the present attitude of the individual. The question will naturally be asked, "What can the individual do in this matter to aid the industry?" [illegible] be obtained at home to the advantage of our own countrymen.

Already some difficulty has been experienced in obtaining manufactured goods which up to the present time have been imported and sold through British agents or [illegible] the deficiency can be met by many existing firms in this country who have tried in the past to obtain their proper share of the market, but unfortunately have had to abandon the effort owing to the prices quoted by foreign competitors. It is to be hoped that one of the results of this war will be the diversion of Germany's trade into other channels, and it is our duty to endeavour to secure from other countries the trade which they have hitherto carried on with Germany. [illegible] apparatus from that country alone amounted in 1913 to [illegible] represents exports to England.

Foreign Competition.

I regret to say that the practice of many large purchasers of securing material at the lowest price, regardless of quality in many cases, has helped foreign trade to the detriment of the British.

[illegible] with those of [illegible]

[illegible]

[illegible] markets of his own country and of the world is a surety of good work, and his experience of this country's [illegible] ments is undoubtedly worthy of recognition. [illegible] they will now rise to this unparalleled opportunity and assert their superiority, and so regain permanently the trade that of late years has eluded their control.

British engineering as a whole is recognized as sound in principle, although perhaps slow in taking up any change of policy; consequently it must be our earnest endeavour to develop the electrical section of this great industry on live, stable, broadminded, and progressive lines.

The feeling of patriotism that has latterly united all classes of men in upholding our position as a nation in this crisis needs to show itself in the commercial world. Then, I venture to think, the industry in [illegible]

The Influence of Patriotism.

At this stage the importance of endeavouring to keep our manufacturers' works open, and their staffs in full employment under the existing adverse conditions, is fully realized by those who have the welfare [illegible] at heart. Consequently all purchasers, wh[illegible] small, who have orders to give should n[illegible] [illegible] done, and are doing, whole-heartedly, all in their power to supply men and material to help the Mother Country in the terrible conflict which has been forced upon her. I think one may say without hesitation that the same [illegible] trade campaign to a successful issue. At the same time [illegible]

portion of the trade which Germany has taken from us during the last 10 or 15 years.

Instinctively in the midst of war the people of this nation rally round each other, and the sooner it is fully understood that economic pressure can be brought to bear in crippling and stopping German commerce, the sooner will this terrible struggle terminate. The wave of practical patriotism which is rolling over this vast Empire, and the earnest desire of all to help in some degree in national service, require only directing to the sphere of trade to have far-reaching effects. Patriotism rightly directed can be an enormous power in other than military or naval services. The tide of patriotism runs high, but I fear it is not strong enough to be a national defence of our industry. The creation of a nucleus of a demand at reasonable prices in this country and its Dominions, by Governments, municipalities, and large purchasers setting the example of buying in the home and colonial markets, would provide electrical manufacturers with a sound foundation upon which to build and extend the industry. The moral influence of such an example set by these large purchasers would be a very great encouragement to other industrial concerns to do the same. Investment in manufacturing companies would be more attractive, and these in turn would be better able to extend and keep up-to-date in research work and the testing of new processes.

Electrification of Railways.

It is hard to determine why the use of electrical energy has not made greater headway in railway engineering, but I think it may be safely said that, in the near future, applications on a larger scale will come up for consideration as trade conditions generally are becoming more and more severe. By a number of the railway companies electricity is already utilized to some extent, but in no instance to the extent which from its known utility and advantages one would expect to be the case. The question whether the railway companies should erect their own generating stations is one which only they themselves can decide, but I do think that the tendency to erect a number of stations for railway purposes alone would not be progress in the right direction. There are many electricity supply departments of municipalities and companies which are willing and quite able to supply the railway loads at prices as low as, and even less than, the cost at which the railway companies could generate the energy themselves.

It is sometimes argued that railway loads and demands on generating stations are exceptional, and unsuitable as an addition to the ordinary demand on an electricity works. In my opinion this is not so. Some years ago traction work was thought to be somewhat similarly barred, but experience has proved that increasingly heavy power loads can be, and are being, accepted and successfully dealt with throughout the country.

Railway directors have to face the fact that electricity as a motive power is a force to be reckoned with, and if they do not avail themselves of it, it will come along independently in competition with existing interests.

Sound Basis of Trading.

I should now like to say a few words on the important subject of the purchase of electrical plant. The price is one of great importance, and it affects both the manufacturer and the purchaser. The solution can never be reached until the manufacturer and the purchaser mutually agree to consider the bargain from each other's standpoint; always bearing in mind that the price is not the primary consideration, but rather efficiency, reliability, and sound mechanical design. The manufacturer knowing the output of his own works can supply plant in many cases of only a certain design and capacity, and he is too often hampered by specifications insisting on alterations in details and trivial conditions with which it is impossible to comply except at greatly increased cost, frequently involving a loss on the contract.

When plant is required it seems to me essential that the purchaser should state fully what will be its duty when in commercial use, but he should not specify the design, material, method of construction, and other similar matters, which are surely the concern of the manufacturer, who should be left to give the purchaser the benefit of his greater experience in all these matters of detail. Of course it must be granted that this principle could be carried so far that progress in design would be retarded, but healthy rivalry would surely stimulate competition and so prevent stagnation.

Labour-Saving Appliances.

Manufacturing operations can be greatly improved by the use of labour-saving appliances. Their adoption, together with the use of electricity, tends to raise working conditions to a much higher level, with consequent improvement in the environment and health of the workers. I think one may claim that wherever electricity can be applied it is the usual motive power with modern labour-saving appliances, and that developments in this direction are becoming more and more noticeable.

Within the last half century there has never been such an opportunity for consideration of this question as at the present moment, owing to the country having to an appreciable extent to rely upon its own resources. The position is that the whole, or nearly the whole, of our requirements have to be or ought to be within our own grasp and control, and any excess of unemployment caused by the introduction of labour-saving appliances in one quarter must suit itself to new trades or occupations. These will have to be commenced in the future so that as a nation we shall be less liable to be adversely affected by external causes.

It has been said, often in bitterness, that labour-saving appliances increase unemployment. This surely is incorrect. Labour is so adaptable that as the supply required in one direction decreases, new openings appear in another. This enlarges the field of labour and ensures the continuity of work. The labour saved as a result of the adoption of this class of machinery is available for the manufacture of additional articles now imported, or for employment on the land. More workers on the land would add greatly to the prosperity and stability of the markets of the country, and at the same time a larger population would be living under more healthy and comfortable conditions.

Smoke Abatement.

During the last few years the question of smoke abatement has been more and more brought before the public

[illegible]

If we consider the amount of fuel used for the banking of boiler fires each night and the opening out every morning, also the quantity required for week-ends in a manufacturing town of moderate size, I think we shall find that the cost, exclusive of labour, must be such that if the amount were expended on the purchase of power from an [illegible]

[illegible] manner.

[illegible] been remedied.

CONCLUSION.

In [illegible] applications to the notice of the public. To do this the engineer, whatever his position may be, must not only keep up-to-date with the progress of the electrical industry in his own country, but must also watch developments in other countries, so that the efficiency of any work that he undertakes may be always of the highest order.

YORKSHIRE LOCAL SECTION: CHAIRMAN'S ADDRESS

By T. Roles, Member.

[illegible]

The choice of suitable subjects for addresses must become yearly more difficult to those members of the Institution who are elected chairmen of Local Sections. Previous addresses have covered exhaustively the very wide field of electrical engineering, and it is therefore becoming more difficult for chairmen to strike absolutely fresh ground unless they are engaged on some new development of the industry.

The general manager of an electricity supply undertaking of any considerable size, even where he combines with that office the position of consulting and resident engineer, can hardly be expected, in view of the diverse duties of such a post, to have specialized in some particular technical branch of the work, as he would thereby be liable to lose grip of the general control of the concern for which he is responsible.

The various problems incidental to the provision of a public supply of electricity on a more or less large scale have been extensively dealt with in addresses during recent years; I therefore feel debarred from taking such problems as the subject of my address, although from the business point of view I am naturally most interested in them. However, in the present serious crisis through which our country is passing I find it difficult to turn my attention to anything other than the war and its effects, so that I propose to make a few remarks on this subject from the point of view of the electrical industry.

Dealing first with the personal duty of our members at this juncture, I would suggest that the first question each one of us who is of suitable age and build and is in good health should ask himself is: Should I take up arms for my country? This question is not always an easy one to answer, and it demands careful thought before a decision is reached. The Army has vital need of many more men than have yet enlisted, but it must also be remembered that were it not for work which must be carried out at home throughout the period of the war our army abroad could not exist. In much of that work the electrical industry is closely concerned. Treating the matter strictly [illegible] better by bearing arms or by remaining at home to carry out work which though more prosaic is equally necessary.

Our electricity supply undertakings must be kept going, otherwise the activities of factories and mills which are turning out material of all descriptions for our army and navy will be stopped or considerably retarded. [illegible]

run these undertakings. Others are doubtless engaged with firms which are manufacturing war material or goods needed directly or indirectly for the campaign, the work in regard to which must be pushed forward in the most efficient and energetic manner.

Having considered these facts and satisfied himself that he is in every way fit to bear arms, the patriotic electrical engineer should consider whether the position that he holds can either be left vacant for the period of the war without detriment to the country's immediate interests, or whether it can be filled without serious loss of efficiency by another less well able to bear arms or who has stronger personal ties. If the position can be left vacant or reasonably well filled, it seems apparent that the place of the electrical engineer is in the fighting line.

The actual branch of the army to be selected must be a matter of the judgment and, as far as duty will allow, the inclination of each engineer. The technical corps are apparently well filled, but it is to be hoped that electrical engineers will not hold back because they are unable to assist the military anthorities in work of an engineering character. The training received by an electrical engineer should enable him to display individuality in a marked degree and should assist considerably in any military operation, to the country's advantage in any case and probably to his own in the direction of promotion.

With regard to the immediate duties devolving upon those electrical engineers who remain in civil life, I suggest that some of the most important of such duties are :—

(1) To execute with energy any work which is in any way connected with military requirements.
(2) To assist by all means in their power persons who are anxious to join the military forces in the attainment of their desire, and to encourage those who are capable of bearing arms, and are in a position to do so, to enlist.
(3) To assist and encourage all efforts made to contribute towards the comfort of our troops on active service and the welfare of their dependents at home.
(4) To support the sentiment "Business as usual" with regard to the electrical industry in particular and to all other British industries in general.
(5) To further the efforts which are being made by British manufacturers to capture and retain such foreign and colonial trade as has hitherto been in the hands of the enemies of this country.
(6) To consider carefully the methods of educating and training young electrical engineers with a view to reorganizing and improving such methods, so that in future the design and manufacture of all electrical apparatus required for the Naval and Military Services shall be carried out by British-born subjects. Special attention should also be given to business training, so that the methods of British firms may be entirely up-to-date and their sales organization controlled by our own countrymen.

Examining the above duties more in detail, it may be stated with reference to the first, that those of us who are actually engaged on work required for military purposes should remember that very much may depend on the work of the humblest worker, and that time is now the essential factor. Never, perhaps, in the history of the world has inferior workmanship in connection with a small detail of apparatus, or delay in the delivery of a machine, had such far-reaching results as it may have to-day. It therefore behoves each of us to do his best in carrying out all such work, and, if necessary, to deny himself leisure and recreation in order to prevent delay in delivery.

The second point is one chiefly for the consideration of employers or those in control of men. It is undoubtedly the duty of such persons at the present time to assist and encourage their employees to enlist, provided that delay in carrying out Government contracts or risk of failure of the public services will not result. Fellow employees can render valuable assistance by instructing new comers in the work of the positions vacated by their colleagues who are leaving to fight on their behalf; and they must remember that if volunteers do not come forward a levy must sooner or later be made by the Government on the manhood of the country. If by working overtime employees can facilitate the early departure of those desirous of leaving for military service, they are rendering assistance to their country. Employers should also accept in a patriotic spirit any inconvenience caused by men leaving to enlist.

A word of advice to our younger members who wish to serve their country in the fighting line may, however, not be out of place. However good their intentions may be they should not vacate any post, especially in an undertaking rendering public service or a firm manufacturing goods for military purposes, without giving such notice as will allow their employers reasonable time to fill their positions.

Our duty in regard to the third point is obvious. All of us must have read of the many discomforts endured uncomplainingly by our troops. All agencies for supplying reasonable comforts to our men should therefore be strongly supported by our members. The least that can be expected of those who remain at home is that they should assist in bearing the burdens of the men at the front, and I would earnestly request those who have not so far arranged to do so to contribute regularly during the period of the war, and as long as necessary after its conclusion, a definite percentage of their incomes to the relief funds for assisting persons affected by the war.

I also suggest to our members that they should do everything possible to impress on our legislators the necessity of at once making provision for those incapacitated during the war and for their dependents, and also for the widows and dependents of those who have fallen. This is a matter that should not be left over to be dealt with at a later date. A definite and adequate scale of pensions should be decided on immediately, and should be paid whatever the cost to the country. Our reward will be the thanks of those who have done so much for us, and the accession to the Services of large numbers of willing recruits.

Many employers have arranged to pay those employees who are performing military or naval duties a proportion of their usual salaries or wages during the period of those duties. Such patriotic action has decided many men to enlist who otherwise could not have seen their way to do so, and has relieved the minds of many Reservists who have perforce had to rejoin the colours whatever their feelings

[illegible] as to provide for the additional expenses which may be [illegible]

The aim should be to provide work for all in this country [illegible] so that full advantage can be taken of improved conditions by turning out large quantities of the best possible goods.

While trade is slack obsolete plant should be replaced and improved methods of driving adopted. If manufacturers with spare capital will adopt this course, the electrical industry will benefit at a critical time and the manufacturers will reap their reward later. If some scheme could be devised and put into operation whereby manufacturers having a limited amount of capital could obtain new plant on reasonable terms, the country in general would benefit both immediately and in the future.

Electricity supply authorities in particular should carry [illegible] sary, thereby providing work during any periods of depres- [illegible] of keeping ahead of the demand during recent years has given engineers in charge of such undertakings little time to consider many details which would amply repay attention; a period of slackness may therefore be profitably utilized by them to examine critically their plant, to install various devices which would tend to bring about economy in working, and to carry out schemes of extension. Those who pay strict regard to economy may be also influenced by the fact that the cost of plant and materials will probably increase immediately a boom in trade is experienced.

I am of opinion that by gradually increasing within reasonable limits their stocks of meters, motors, and other apparatus for letting on hire, during any period in which trade in the electrical industry is at a low ebb, central [illegible] there will be rapid electrical developments.

[illegible] A careful study of the requirements of customers abroad would appear to be the first necessity, after which our designers and workmen must endeavour to meet such requirements [illegible] possible to reduce the cost of manufacture while retaining the British reputation for good workmanship and reliable products.

Whatever opinions may be held in regard to purchasing goods from abroad during normal times, there is little doubt that in the present crisis everybody will see the necessity of obtaining wherever possible from British firms any electrical machinery or apparatus that is required, even if considerably more favourable terms are offered by competitors in neutral countries.

The last of the duties set out earlier in this address appears to me to be of extreme importance to our industry. The great extent to which the electrical industry has relied on foreigners for the design and supply of electrical and even mechanical apparatus is well known. A considerable proportion of such apparatus has no doubt been purchased abroad owing to the low prices at which it has been offered compared with the prices quoted by British manufacturers for similar goods. I do not here propose to discuss dumping or tariffs, but merely wish to call attention to the fact that a large amount of foreign trade has been obtained on the merits of the goods supplied. The electrical industry of this country is undoubtedly much indebted to foreign inventors and designers for the headway which has been made during recent years. I may mention the metal-filament lamp, the flame arc lamp, the steam turbine, the high-speed alternator, and the magneto, as a few instances where progress has been made by their aid. The large number of master patents taken out in this country by foreigners show how largely we are dependent upon the engineers of other nations for electrical inventions and the design of electrical apparatus.

If we consider electrical apparatus and machinery manufactured in this country we shall be surprised to find to what a large extent British firms work to designs originally obtained from abroad, and to learn that in many of our large works one or more of the chief designers are of foreign nationality. I admire the genius and capabilities of these men. A number of them are at the present time designing and supervising the manufacture of electrical machinery directly or indirectly required by the

Government for military or naval purposes, and it is doubtful whether we could do without their aid; at the very least we should be much inconvenienced by their departure. Is it wise that we should be so dependent upon foreign designers and foreign-made apparatus not only in connection with Government requirements but in the industry generally? I do not wish to suggest that the majority or all of the aliens holding important positions with our manufacturing firms, and who are in many cases members of our Institution, are not honourable men. I feel convinced that they are; but the fact that they are honourable makes their position more difficult for them at such a time as the present.

Before the outbreak of this war it was argued by many that patriotism was an out-of-date creed, but I have always inclined to the opinion that in the heart of every true man the spark of patriotism existed, and that it would burst into flame in any crisis which affected the vital welfare and perhaps even the existence of his country. Is it logical, therefore, to suppose that a foreigner can put his whole heart and soul into work required for the assistance of his country's enemies, even if among the latter he has many personal friends?

How is it that such important posts in our manufacturing firms are occupied by persons of alien birth, either naturalized or otherwise? It cannot, I think, be suggested that they are content to accept lower salaries than British engineers. There seems therefore only one answer to my question, namely, that such persons are more capable in their particular line than the home-trained engineer. Only two reasons can be given for this greater capability—either the British temperament, speaking generally, is not such as to conduce to deep study of intricate subjects and to provide the concentration of thought needed by the inventor and designer; or else our educational system is not such as will bring forth the latent abilities of the student.

If the former suggestion is correct, there is of course no hope of eliminating alien inventors and designers from our works, or of our country taking a leading position in the invention and design of electrical apparatus, and we must be content to endeavour to improve upon, and make more practical and reliable, inventions brought out abroad.

On the other hand, if our educational system is at fault, it is time that the system was revised. I have not made a study of educational methods, but it seems to me that better results might be obtained if the higher branches of electrical and mechanical engineering were taught at a few extremely well-equipped centres in this country by well-paid professors having the very highest technical qualifications, instead of each large town endeavouring to provide such facilities at technical schools.

To illustrate my meaning I would cite Leeds and Bradford; each city has a well-equipped engineering laboratory, the first mentioned at the University, and the second at the Technical College. If the two cities agreed to unite their classes in these subjects at one centre, it would appear that much overlapping and unnecessary expense could be prevented, and the saving effected could be utilized in giving financial assistance to those students who would find it necessary to travel from one city to the other, as well as in providing a more complete and expensive equipment and better educational facilities generally.

I suggest that the educational question is one which might with advantage receive in all its bearings the very careful consideration of our Institution.

With regard to business training, there seems to be a fairly general feeling that British commercial methods frequently compare unfavourably with those of foreign firms. However this may be—and I am in no position to express an opinion on the matter—the fact remains that if we are to obtain the share of the world's electrical trade which we desire, our business organization must be thoroughly up-to-date. We may manufacture the best of goods, but without skill in our sales departments the major portion of them will probably remain in our warehouses. The true salesman is said to be born, not made, but in order that he may obtain the maximum success his natural ability should be supplemented by a sound business education obtained in a systematic manner and not picked up haphazard whilst carrying out other duties. It would seem especially desirable that all persons who are employed in our sales departments should be of British birth, as under such circumstances there would be far less chance of valuable business information being conveyed to foreign firms than under the present conditions.

In conclusion, I may say that whether they agree with many of my remarks or not, I feel sure that the members of the Yorkshire Local Section have the true interests of their country and profession at heart, and especially in this period of stress will give unsparingly of their time and energies in promoting those interests in ways that they individually consider most suitable. Should any remarks of mine tend to assist them in their endeavours in the smallest degree I shall be very gratified.

SCOTTISH LOCAL SECTION: CHAIRMAN'S ADDRESS.

By James Lawson, Member.

([illegible])

[illegible]

[illegible]

[illegible] belong is one of the principal participants. Although this country is not the actual scene of operations, yet the grim realities of war are being daily brought before us to an [illegible] brothers, colleagues and professional friends, temporarily [illegible] their country's call; all of us in fact have suffered to a [illegible] ultimate result of the struggle, but we naturally find it difficult to keep our attention for any length of time on our ordinary work. Nevertheless, our Institution has, in [illegible] wisely, decided to do its utmost to keep things [illegible]

[illegible] confident that our electrical colleagues who are at the front will continue to give an excellent account of themselves.

It is now quite unnecessary to refer at any length to the advantages, as regards convenience and economy, of electricity [illegible] conclusively that even for tramp steamers it pays to use electric light.

Consider, for instance, the consumption of stores per voyage of a tramp steamer of say 6,000 tons which is lighted by oil. The lighting would consist of the usual two mast-head lamps, the stern lamp, the side lamps, and [illegible] equivalent to £130 per annum for oil alone. Further, at least £50 must be added to this total to allow for the cost of labour in trimming and attention, wick, etc. Then there is also the expense resulting from the poor light and the deposits of soot. It is almost impossible for an engineer to look after his engines properly when [illegible]

[illegible] coal per day would be required. The most economical [illegible] 350 to 450 revs. per min., with broad bear- [illegible] the wires and cables should be distributed on a simple system, armoured and braided cables being used in the hold and in the engine-room, and lead-covered cables in the cabins. A marine engineer who has had no previous experience of electrical work could easily keep such an installation in thorough working order.

[illegible] *Columbia* 115 10-c.p. lamps and two dynamos belt-driven from a counter-shaft. Some months later the Cunard steamer *Servia* had electric light installed at a cost of about £1,000. The *Servia* had 117 Swan lamps and two arc lamps, representing about 10 kw. altogether. In 1883 the S.S. *Nonpareil* was lighted electrically by Messrs. J. H. Holmes & Co., and this was the first ship on the Tyneside to be equipped with electric lighting plant.

For comparison it may be of interest to mention that the well-known White Star liner *Majestic* was fitted in 1899 with 1,200 16-c.p. lamps, and at that time it was [illegible]dered remarkable that the exposed navigation lights and compass lights were electric. The four dynamos were Crompton horizontal compound-wound machines, and [illegible] compound horizontal type, running at 200 revs. per min. The wiring of this vessel was carried out on the single-wire system, with "ship return," and the wires were run in pitch-pine single-groove casings and carefully fixed in the grooves with putty.

The first insulated wires used for ship lighting were covered with cotton cloth and white lead, and were [illegible]

[illegible] dynamos. Belts on board ship are, however, objectionable, on account of the space required and their unsteadiness. Many attempts were made to get over the difficulty of connecting the low-speed engine and the high-speed

dynamo, but these efforts were for a long time unsuccessful, as even friction wheels were found unsuitable for all but the smallest powers. It was this demand for a suitable engine to drive a high-speed dynamo which led to the development of the high-speed engine and the steam turbine. When everything possible has been said in favour of the relative merits of an engine running at 200 and 300 revs. per min. and a high-speed engine at 500 to 700 revs. per min., the steam turbine remains the ideal motive power for electrical generators on board ship because it completely fulfils the particular conditions that there prevail. Its weight is small, it occupies less space, gives a steadier drive, has (above a certain size) a higher efficiency, is comparatively free from vibration (an important factor in passenger vessels), and having no reciprocating parts gives rise to less wear and tear.

The use of electricity in steamers was at first confined mainly to electric lighting, electric bells, and a few telephones. Ten years ago very few electric motors were in use even on fairly large steamers. A decided advance was made in 1907 when the Cunard Company built the *Lusitania* and *Mauretania*. In these vessels electric motors displaced steam engines for driving the forced-draught fans, 16 50-h.p. motors being employed for this purpose. Considerations of space and absence of noise and vibration were the main factors in the decision to use electric motors in this case, but in other parts of the ship electric motors and apparatus were used because, in addition to the other advantages, the supply cables could be installed without disfiguring the interior decorations and without the risk of causing damage such as would occur at leaky joints in steam pipes.

The following summary will give some idea of the size of the installations on these ships :—

In the *Mauretania* there were—

16 motors, aggregating 800 h.p., for forced draught.
29 „ „ 276 h.p., for ventilation of the machinery space.
18 „ „ 400 h.p., for auxiliary machinery in the engine-room.
16 „ „ 52 h.p., for ventilating the ship.
53 „ „ 156 h.p., for the thermo-tanks supplying the heated air.
4 „ „ 64 h.p., for refrigerating machinery.
2 „ „ 16 h.p., for two passenger elevators.
4 „ „ 108 h.p., for lifeboat winches.
8 „ „ 48 h.p., for electric jib cranes.
6 „ „ 78 h.p., for mails and baggage hoists.
6 „ „ 20 h.p., for hoists for stores.
2 „ „ 10 h.p., for printing machinery.
1 motor of 5 h.p., for wireless telegraphy.

Electric power to the amount of 20 h.p. was also used for pantry and kitchen service and for hot-plates, and 80 h.p. for 106 electric radiators for special state-rooms, bathrooms, and hospitals, making a total of 2,133 h.p. of motors, independent of the power for lighting, or 1,333 h.p. independent of 800 h.p. used for forced draught.

It will be noted that the life-boat winches were operated electrically, but electricity was not used to any great extent for cooking and heating. In the application of electricity to cooking and heating on board ship there is still a large field for further extensions, but for complete success strenuous endeavour and enterprise on the part of the electrical industry will be necessary.

It is hardly surprising that the adoption of electric cooking has been comparatively slow on board ship. For a long time suitable apparatus was not available; and it has also to be borne in mind that as regards cooking and heating, electricity has a formidable rival in the abundant supply of steam always obtainable on board ship. Here again, however, the disadvantages inseparable from other methods tell in favour of electricity. Where coal is used in the kitchen of a large liner, at least 30 h.p. of motors are required in continuous use to drive fans for cooling the galleys. On the other hand, the initial cost of electric heating is undoubtedly higher than with rival systems. Over and above the heaters themselves, special cables and additional generating plant have to be provided. The low voltage usually employed on board ship renders it necessary to use larger cables for heating circuits, and this means extra expense. The running cost of electrical apparatus is also higher, as steam can be obtained at a low cost from the boilers, which are generally situated close to the cabins, where the heat is most likely to be wanted. Notwithstanding these objections, however, the prime considerations of comfort, convenience, and æsthetic effect, result in electricity being more and more used for heating, and its universal adoption on board ship is only a matter of time.

The thermo-tank system of heating and ventilation has been much used for large spaces, such as the compartments of third-class sleeping berths. In this system (invented by a member of this Local Section) an electric motor drives a fan which forces air through a steam heater (or brine cooler if cooling is required), the air being distributed by air trunks. With by-pass and other valves very fine regulation is obtained. The system is always under control and the foul air can be exhausted at will. Being partly electric, the system naturally appeals to electrical engineers.

Another system which is used for heating is even more difficult to compete against. In this system low-pressure exhaust steam is drawn through small tubes by a vacuum pump placed at the remote end of the system. The running cost of this system is practically nil, as an otherwise useless by-product, namely exhaust steam, is utilized.

The steam engine is particularly suitable for use with winches, as it is able to withstand rough usage and even total immersion in sea water, and it will therefore be a difficult matter to oust it from its present position. The electric winch as at present designed has not the same qualities to recommend it, but it should not be impossible so to improve this winch as to make it preferable in every way to the steam-driven one, in view of the fact that electric cables have many advantages over steam pipes on board ship. On large passenger liners where forced-draught fans are driven electrically when the ship is not in port, the load factor would be greatly improved by the use of electric power to operate winches, cranes, etc., at times when the forced-draught fans would not be in operation.

The advent of motor-driven ships, of course, makes the use of electric auxiliaries imperative, and at least one steam-propelled ship, the G.S.N. Company's *Fauvette*, has recently

been equipped with a complete set of electric cranes for discharging and loading cargo.

An interesting experiment in electric marine propulsion by alternating current was made on the Clyde a few years ago, and following this a [illegible] ocean-going vessel was designed and [illegible] equipped at Newcastle on Mr. H. A. Mavor's system. Unfortunately, during the time that elapsed between the design and the completion of the vessel the commercial conditions changed to the disadvantage of oil engines. The price of oil fuel was nearly doubled, and this so changed the commercial prospects that it was decided not to proceed with the enterprise on the lines originally intended.

S.S. "Aquitania."

Other applications of electricity on board ship are so numerous that I do not propose to refer to them in detail, but will rather do so incidentally in the following brief description of the electrical equipment of the Aquitania [illegible] which is of particular interest owing to the large number of electric devices that have been used for the first time on this vessel.

Electricity was employed [illegible] in the preliminary operations, 14 electric [illegible] being erected along both sides of the building berth. When the vessel came to be launched the same power was adopted for releasing the triggers of the launching gear, as well as the mechanism for breaking the ceremonial bottle of wine against the side of the ship.

The overall dimensions of this vessel are 901 ft. × 97 ft. × [illegible] ft. Accommodation has been provided for [illegible] passengers and a crew of [illegible], making a total of [illegible] persons.

Generators.—The generating station is in a compartment placed between No. 3 and No. 4 boiler rooms. The generators consist of four British Westinghouse [illegible] kw., 1,500 revs. per min., 225-volt continuous-current turbo-generators with slip-rings and static balancers for 3-wire distribution. These static balancers were designed to deal with an out-of-balance current in the middle wire equal to [illegible] per cent of the full-load current of the machines. Each turbine can work up to [illegible] per cent overload when supplied with steam at a pressure of 150 lb. per sq. in., and exhausting against a back pressure of 20 lb. per sq. in. absolute. The turbines are of the standard impulse type and have three running wheels, each carrying two rows of blades.

The generators are fitted with radial commutators and ventilated brush-gear. To ventilate these generators air is conveyed in sheet-steel ducts from the top deck, the ducts being led below the bedplate of the generators. Special in-take pipes are provided at the turbine end of the generator to supply air to the armature and field, and at the outboard end of the generator to supply air to the brush-gear. Each generator is fitted with fans capable of forcing a sufficient quantity of air through the machine to keep the temperature rise of all the parts within the specified figure of [illegible] C. The turbines are fitted with emergency governors which come into operation when the speed rises 10 per cent above the normal and cut off the supply of steam.

The 3-wire system has been adopted, with a pressure of 220 volts across the outer conductors and of [illegible] between the neutral and each outer conductor. [illegible] the adoption of this system apart from the saving of copper [illegible] the reduction in the size of the commutators of the generators and motors [illegible] the fact that the number of [illegible] required on each generator is approximately one-half of the number required with [illegible] and the [illegible] [illegible] With the [illegible] of positive [illegible] the [illegible] at a pressure of [illegible] volts, and with the voltage [illegible] [illegible] [illegible] [illegible] [illegible].

Main switchboard.—The main switchboard [illegible] and is designed for the control of four generators, together with their static balancers, 10 feeder circuits for lighting and 14 feeder circuits for power. For each generator there are two circuit-breakers of 3,000 amperes capacity, fitted with a time-lag attachment on the overload release. [illegible] placed on the instrument panel in the centre of the board. [illegible] These large circuit-breakers are placed on the outer ends of the board, as nearly as possible opposite to the generators, while near the centre there are two panels containing the instruments, a shunt regulator, a balancer switch, a remote control switch, and a middle-wire ammeter for each machine.

The centre panel is devoted to the middle-wire feeders. These are coupled direct to the neutral busbar through [illegible] to its own central-zero ammeter. The neutral bar is connected to earth through a central-zero ammeter, a variable resistance, and the main switch; and a contactor, the use of which will be referred to later, is fitted in parallel with this switch.

The feeders are provided with a circuit-breaker on each pole, time-lag devices being fitted in all cases, and above each pair of circuit-breakers a 2-way double-pole [illegible] introduced in each feeder and is connected to the 2-way switch so that the ammeter may be used for either a [illegible] placed between the instrument panels in the centre and the generator circuit-breakers at each side.

Referring now to the middle-wire earth switch and the contactor in parallel with it, normally these switches are open and the installation runs with an unearthed [illegible] cord. It is thus possible to stand in front of each feeder [illegible] instrument. If the fault is not observed in the negative

feeders, the 2-way switches are changed over to the positive feeders and the operation is repeated. In order to guard against the overloading of the balancers, the positive and negative circuit-breakers are coupled together by connecting rods so as to ensure both being tripped simultaneously.

Main cables.—Power is transmitted from the main switchboard to 14 220-volt auxiliary switchboards and also to 10 3-wire auxiliary switchboards for the 110-volt supply. These boards are placed at different positions on the port and starboard sides, and cross-connecting cables are provided, so that in the event of failure of one section the supply can be maintained from the other side.

Wiring.—The total length of the single wires installed amounts to approximately 135 miles, and of the stranded and multiple cables to 65 miles, making in all about 200 miles of cable. The gross weight of all the wires, including their insulation, is estimated to be about 50 tons, and the total weight of copper to be about 25 tons. If rolled into a No. 16 S.W.G. wire it would stretch over 800 miles. The largest cable is of 0·75 sq. in. cross section, and there are about 5,600 yards of 0·5 sq. in. cable and several lengths of 0·35 sq. in., 0·3 sq. in., and 0·25 sq. in. cables. Something like 90,000 porcelain insulators and 100,000 screws have been used in the work.

With a view to preventing the possibility of a fire starting owing to a failure of the electrical installation—and such fires have undoubtedly occurred—special precautions have been taken in regard to the mains, sub-mains, and branch wiring, and the woodwork of the ship has been specially constructed so as to contain the wires and give easy and rapid access to them. Special care was taken to keep all positive and negative wires in separate grooves. The main feeders and 220-volt cables are fixed close together in small clamped insulators, and all cables are insulated with the highest-grade vulcanized indiarubber, so that it is confidently anticipated that their life will at least be equal to that of the vessel. It would certainly appear as if nothing short of an accident would injure them. It should be noted, however, that the life of a cable depends to no small extent on the care with which its position on board ship is selected, and to the care taken in installing it. This result can only be ensured by employing thoroughly reliable wiremen and a staff of trained supervisors. In the *Aquitania* the leads for wires were designed so that a workman would find it difficult to place the wires in any other position than that definitely arranged for them; while in order that the various circuits should be easily traceable, the wires are of different colours.

Power installation.—Time will not permit me to refer to all the applications of electric power on board this ship; I therefore propose to give the following tabulated list of the motors which have been installed and the purposes for which they are used :—

14	motors,	aggregating	700 h.p., for forced draught.
3[illegible]	,,	,,	479 h.p., for ventilation of machinery spaces.
17	,,	,,	333 h.p., for auxiliary machinery in engine-room.
52	,,	,,	182 h.p., for ventilating the ship.
36	,,	,,	205 h.p., for thermo-tanks supplying heated air.
5	motors,	aggregating	42·5 h.p., for 1st and 2nd class passenger lifts.
2	,,	,,	60 h.p., for life-boat winches.
4	,,	,,	46 h.p., for electric jib cranes.
2	,,	,,	30 h.p., for mail and baggage lifts.
3	,,	,,	22·5 h.p., for stores and service lifts.
2	,,	,,	2 h.p., for printing machinery.
8	,,	,,	8 h.p., for gymnasium.
1	motor	of	1·5 h.p., for sounding machines.
1	,,	,,	2 h.p., for a gyroscope.
1	,,	,,	10 h.p., for a deck winch.

There is also 131 horse-power of culinary apparatus, including 2 electric grills, dough mixers, dish-washers, toasters, etc., a number of which are motor driven; 7 h.p. for log fires; and 10 100-ampere shore-winch connections.

The total number of motors is therefore 200, aggregating 1,890 h.p., together with 700 h.p. for forced draught. These motors range from $\frac{1}{2}$ to 50 h.p. each, and the cables for them are for the most part supported on insulators as previously described, and with one or two exceptions all motors are wound for a pressure of 220 volts and are connected to the outer conductors of the 3-wire system. Compared with the *Lusitania* and the *Mauretania* it will be noticed that while there are fewer forced-draught fans, there is a considerable increase in the horse-power required for ventilation, etc.

Lighting.—Metal-filament lamps have been used throughout for lighting, except in the engine-rooms, boiler-rooms, stores, and in the case of portable lamps and clusters. Nearly 10,000 lamps have been installed, and these are supplied at a pressure of 110 volts, the load being as nearly as possible balanced on either side of the 3-wire system. Along each side of the vessel there are also 10 life-boat lamps, each of 300 c.p., which provide light for the boat deck; when necessary, these lamps can be inclined outwards so as to illuminate the ship's sides. These lamps are operated by contactors, which are controlled by switches placed on the bridge. There are also four 100-ampere connections for searchlights.

All the fittings were chosen with a view to obtaining glassware that can be quickly removed for cleaning and for the renewal of lamps. The main entrance, writing room, dining saloon, and foyer have been fitted with 6-light fluted glass dishes, mounted on a new type of bayonet fixture which allows the glass dishes to be instantly removed. The lounge has been lighted by "sunflower" fittings of special design, together with about 200 linolite lamps around the base of the raised roof in the centre. The well in the dining saloon is lighted by four large dolphin motives in the corners, four smaller fittings of similar make in the centre, and two large fittings on the floor level in the form of a water fountain, but with an alabaster shell basin containing lamps instead of the ordinary basin and jet of water. These fittings were mainly designed to illuminate the paintings on the ceilings. The smoking room has lanterns of handsome appearance together with linolite lamps in domes. All the second-class rooms are fitted with glass fittings close to the ceiling, giving a very soft lighting effect, and the swimming bath has been illuminated in the same manner. Sign lanterns to the number of 120 are

[illegible]

Martin's patent duplex automatic masthead and side-light indicator. [illegible] and one wire for the return current from either filament. [illegible] lampholder. The indicator is so arranged that when a [illegible] cause, the magnet armature falls and switches into the circuit (1) the reserve filament, (2) the indicator light, and (3) the alarm bell, the three operations being simultaneously effected. In order to stop the bell ringing, the officer pushes up the barrel switch, and as this operation inserts the magnet in the reserve-filament circuit, the barrel [illegible] filament is not screened strictly in accordance with the Board of Trade Regulations, a new lamp must afterwards be fitted as soon as possible. Should both filaments fail, the bell can only be stopped by disconnecting the circuit. Only shunted bells are used with this apparatus. The current for the indicator flows through a change-over switch and is obtained from either the port or starboard [illegible] gating lights.

For communication with other vessels at night two Admiralty Morse signalling lamps have been fitted, one on the masthead and the other on the flying bridge. Two electrically-controlled whistles are fitted on the funnels, and these whistles are equipped with an electric time-con[illegible]

An Evershed patent electric helm indicator shows on the bridge every movement of the rudder and the angular position of the latter. The 2-h.p. motor used on the gyroscope is operated in connection with the instrument for recording oscillations of the ship. A submarine signalling apparatus is fitted, the receivers being placed in a small telephone cabinet on the bridge.

[illegible] information of the engineers.

[illegible] the ship's time according to the longitude is independent of the operating officer.

[illegible] between the following positions:—

(1) [illegible] position being provided with a 2-way change-over switch to connect the after-docking bridge.

(2) From the upper and lower bridges to the starting platform in the engine-room and the steering gear, and from the latter position to the chief [illegible]

(3) [illegible] office, condenser-room, dynamo-room, pump-room, refrigerator, and steering gear.

On the upper and after-docking bridges each instrument is mounted within a polished metal hood secured to a brass pillar, the hood, which is of a new design, [illegible] systems is supplied with electrical energy from a battery of six large cells, giving a pressure of 9 volts.

For the use of the captain, chief engineer, purser, doctor, stewards department, and other officers, 27 intercommunication telephones have been installed. It will [illegible] with one another, and on arrival in port the [illegible] on the ship was connected to the Liverpool or [illegible] service instead) an exchange has not been fitted on the [illegible]

[illegible] the sides of the indicator. In the top section a buzzer [illegible] push in a state-room drops the shutter [illegible]

the current in the primary causes the shutter to drop and the relay to close, thereby switching in circuit a [illegible] lamp. This lamp is specially constructed and is situated in the alley-way immediately opposite to the indicator. The lamp is made with two red bulls' eyes, which shine down the alley-way in each direction and show the attendant which indicator has been operated; while a third lens in the lamp shines on the indicator and lights it at night-time. By operating the replacement rod the light is switched off. The other switch referred to is for use when the stewards are off duty, the call being transferred to the "master" indicator. The comfort and convenience of the passengers have thus been carefully studied so that they will not be disturbed by the ringing of bells during the night.

Emergency set.—A separate circuit of 700 lamps is connected to the emergency set, these lamps being distributed throughout the public rooms and passages on 10 decks, so that in the event of failure of the main generating plant sufficient light would be provided to enable passengers and crew to find their way about. The life-boat lamps and deck lamps, and of course the wireless apparatus, are all connected to this source of supply at times of emergency. Under normal conditions current is supplied from the main generator, and when it is required from the emergency set a change-over switch has to be operated. The emergency plant is situated at the after end of "A" deck, far above the water-line, and it consists of a 45-b.h.p. Diesel engine coupled to a 30-kw. Westinghouse generator. A special switchboard is fitted alongside the plant.

Marconi wireless installation.—The wireless station is situated on the boat deck amidships, and is designed to provide a working range by day of 650 miles over open water when employed with an aerial having a mean height of 130 ft. The maximum range by night under favourable conditions will be at least twice that by day. The aerial consists of four parallel wires evenly spaced on ash suspenders and stretched between the masts. The earth connections are of insulated copper, and are connected to convenient points in the hull.

One other interesting innovation is the provision of two Thornycroft motor-boats fitted with Marconi wireless installations, by which they can communicate with other vessels when afloat—a valuable provision in time of emergency. The aerial wires are carried on two 25 ft. bamboo masts, which may be lowered on to the decks when not in use. The receiving range for these motor-boats is 300 miles.

In conclusion, I should like to draw attention to the importance of recent applications of wireless telegraphy to shipping, as, for instance, the transmission of weather reports and time signals, the location of ships in distress, and in various other directions which are well known.

ELECTRIC COOKING AND HEATING IN PRIVATE HOUSES.

By W. A. GILLOTT, Associate Member.

(*Paper received 21 March, and read before the* NEWCASTLE LOCAL SECTION *4 May, 1914.*)

ABSTRACT.

If properly installed, electrical cooking apparatus will compare very favourably with other cooking appliances, in regard both to cost and to actual results.

With a few exceptions, electrical manufacturers have shown a tendency to standardize the ordinary type of gas cooker and merely to replace gas burners, etc., by electrically-heated elements, the reason probably being that it is found easier to induce the public to adopt cookers similar in outward appearance to those with which they are already familiar. This practice, however, is entirely wrong, and electric cooking will be to a certain extent retarded in its progress until a properly designed electric cooker is placed upon the market. It seems absurd to tell consumers about the cleanliness of electric cookers and then to supply a cooker with a black outside and numerous crevices in which dirt can accumulate. The author is experimenting with an entirely new design of electric cooker constructed to overcome these difficulties. It is fitted with a horizontal oven, three hot-plates, and a grill; a hot-cupboard also being provided. The outfit stands on four feet, and is giving good results under test.

One of the chief advantages of using electricity for cooking is the ability to obtain exact control, and to place the heat exactly where it is required. When a certain operation has once been performed, it can be repeated at any other time, provided the same elements and switches are used. Therefore, the essential requirement of an electric cooker is reliability, even before efficiency. No consumer would object to use a few extra units per quarter in order to be safeguarded against breakdowns, which may happen at inconvenient times. Failures, however, do happen on the best of cookers; every precaution should therefore be taken to ensure quick replacement of elements.

The demands made on a cooker in the Newcastle district call for apparatus that will stand rough handling and will provide both radiant and convected heat; the former is necessary to give the browning, and the latter for maintaining an even cooking temperature in all parts of the oven.

There are three distinct types of electric cookers which the author has studied very carefully during the last year or so. Table 1 gives a brief description of these ovens, and Figs. 1, 2, and 3 show heating and cooling charts obtained with them. It will be noticed that type A oven reaches a cooking temperature in 20 minutes, compared with 35 minutes for the B and C types. It must be

[illegible]

[illegible] is only heated when it is required, and no time should [illegible] siderable comment upon the amount of heat retained in some types of ovens. The author considers it a distinct

The heating elements are the most vital part of an electric cooker. A great deal of attention has therefore [illegible] reliable. The majority of oven elements are made up of [illegible] elements in the "B" cooker. Since the adoption of this [illegible]

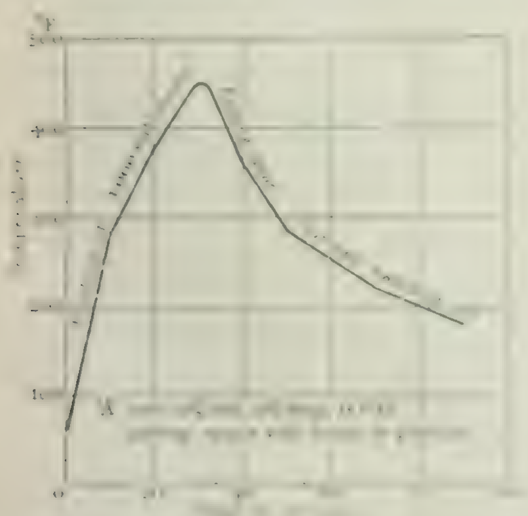


FIG. 1.

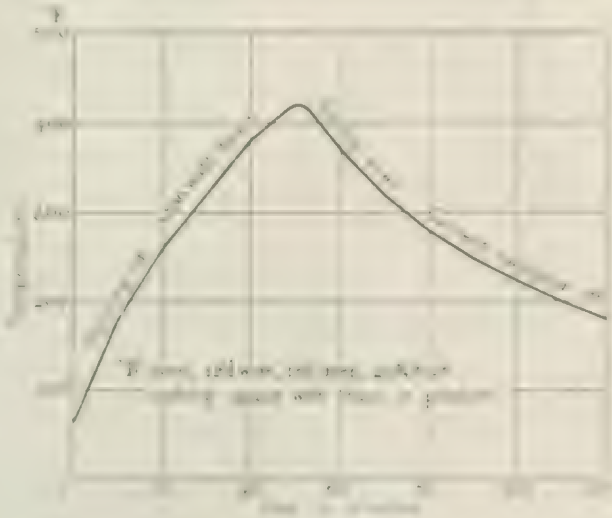


FIG. 2.

disadvantage for an oven to retain its heat for a considerable time after switching off. Some manufacturers make a great point of this. It must not be forgotten, however, that if an oven retains its heat for a long time after switching off, it will consume more energy during the heating-up stage. It is far better to design an oven which will permit of a quick variation of temperature. This feature is necessary under certain cooking conditions.

have been considerably reduced. The expansion of mica [illegible] without straining the wire. These elements are connected four in series and are run at a dull red heat.

[illegible]

at a bright red temperature. This element is the result of prolonged tests, and very satisfactory results are being obtained in actual practice.

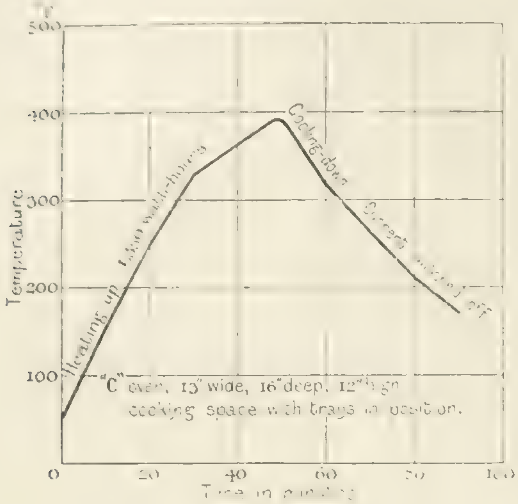


FIG. 3.

The elements in the "C" apparatus are nichrome, or similar non-oxidizing wire, wound on mica formers and clamped tightly between two cast-iron plates.

In Table 2 the total cubic capacity of the ovens is compared with the actual cooking space provided.

TABLE 2.

Cooker	Cubic Inches. Total	Cubic Inches. Cooking Space	Percentage
"A"	4,158	2,110	50·75
"B"	4,845	3,501	72·2
"C"	3,5[illegible]4	2,496	69·3

The relation of the total cubic space to the actual cooking space of an oven should be carefully watched; some makers take up more room in fitting the elements, gates, etc., than others. An endeavour should be made, when a ventilated type of oven is used, to utilize as much as possible of the total space; the bottom rack should therefore be as near to the bottom of the oven as possible. The distance apart of the rack runners should be arranged to provide sufficient room for at least three racks in the oven at one time. This requirement is found absolutely necessary when filling an oven with bread. Gas cookers are very bad in this respect, mainly on account of the amount of space wasted, the flames burning the food if the bottom shelf is placed too low.

Thermometers and lamps inside the oven are of little use. In the case of thermometers it is exceedingly difficult, if not impossible, to obtain reliable readings of the temperature inside the oven. These instruments are very misleading, and become a nuisance instead of an assistance. The practice of fixing a light in an oven is equally absurd. It is impossible to believe that engineers find this an advantage. The life of the lamp is very short and trouble is likely to be caused thereby. It is much better to supply a small book of instructions with each cooker, clearly stating the time taken to heat up. A little experience will soon enable one to know when the food is cooked or requires attention.

HOT-PLATES.

The boiling of liquids in kettles or saucepans on the present type of electric hot-plates is far from satisfactory. The time taken to boil water by this system must be considerably reduced before we can expect to compete favourably with the gas-ring. The great drawback is the slow heating-up of the plate before it actually starts to do useful

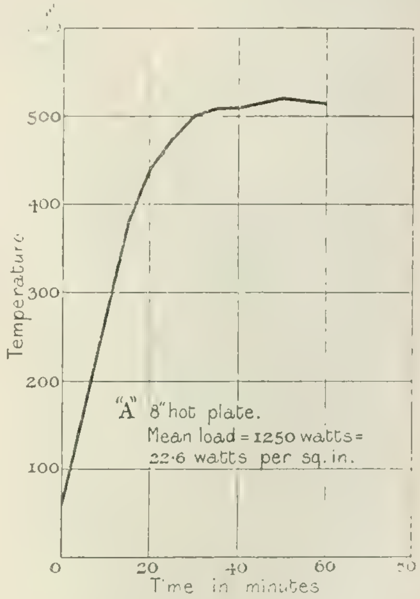


FIG. 4.—Heating-up Curve.

work. Experiments have recently been carried out with a plate giving radiant heat. The top is run at a red-hot temperature and is credited with boiling two pints of water in 11 minutes, starting all cold and using an ordinary kettle. This plate, however, is not yet a commercial proposition, and until something of this nature is placed on the market the ordinary types must be used.

In the majority of cases nichrome wire is used as the heating element, wound on sheets of mica, insulated on both sides and clamped firmly on the under-surface of the plate. In some cases the elements are encased in an armoured envelope. This arrangement is not so satisfactory, owing to the difficulty of ensuring an even bearing surface for the element. This is very important, as if the element is not firmly and evenly clamped against the plate undue local heating will take place and the element will burn out. It is essential that the whole element be kept at an even temperature, thereby reducing the risk of breakdown to a minimum. Further, the relation of the diameter of the plate to the loading in watts should be very carefully watched. If the number of watts

[illegible]

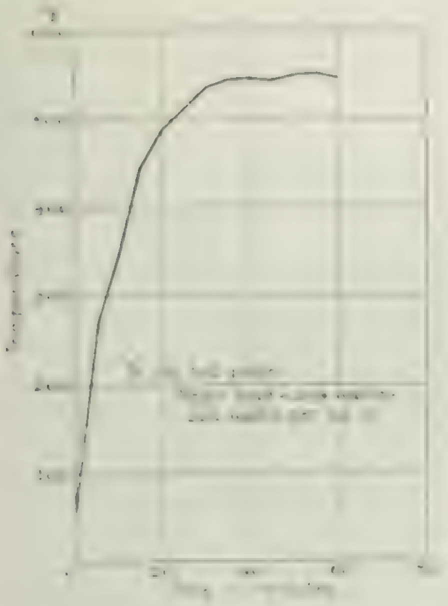


FIG. 5.—Heating-up Curve.

plate as possible. By doing so the tendency to buckle will be reduced. The author has seen hot-plates buckle and crack due to unequal loading setting up unequal stresses.

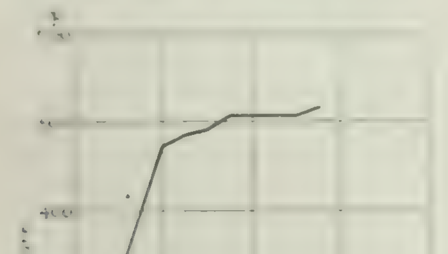


FIG. 6.—Heating-up Curve.

The [illegible] much better results are thereby obtained, nearly double the heating surface being provided. This permits better [illegible] are used the heat is more or less locked up, the plate

[illegible]

TABLE 3.

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

The [illegible] Table 4:—

TABLE 4.

[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	—	[illegible] recorded
[illegible]	[illegible]	[illegible]	—
[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]

The [illegible] important bearing upon the price at which a cooker can be let out on hire. If the apparatus is let out on hire by the supply authority, the latter must either standardize a moderate rental to pay interest on the capital expenditure and charge a slightly higher price per unit to cover repairs, or, vice versa, increase the rental and keep the price per unit at as low a figure as will permit of profitable business. The method adopted will vary according to the district. In wealthy districts if a high rental were adopted it would [illegible] chase the apparatus outright, which is no doubt the best policy for the supply authority; for when the consumer removes to another district he takes his cooker with him. If, on the other hand, it is only hired, the apparatus in [illegible] thorough overhaul and cleaning. This be[illegible] matter when a large number of [illegible] cooker in the house until a new tenant arrives. This prac-

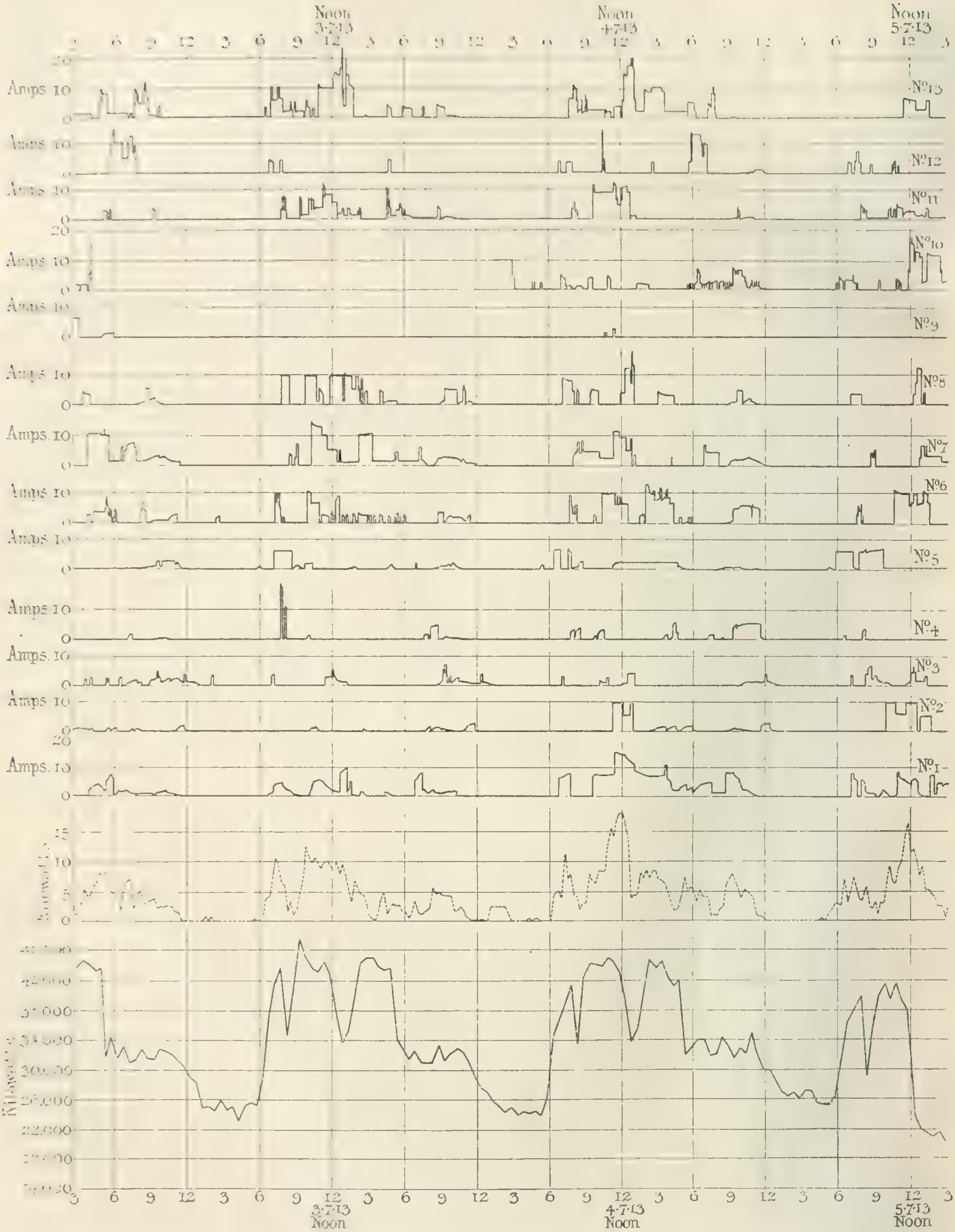

Noon 3·7·13
Noon 4·7·13
Noon 5·7·13
Amps
No. 13
No. 12
No. 11
No. 10
No. 9
No. 8
No. 7
No. 6
No. 5
No. 4
No. 3
No. 2
No. 1
Kilowatts

FIG. 7.

tice could not be adopted with electric cookers on account of the rapid depreciation and their high capital cost compared with gas cookers.

The cost of repairs to electric cookers during the period covered by the manufacturers' guarantee is not of very great importance. It is not until the apparatus has been in use for a few years that really reliable maintenance costs can be obtained. Table 5 gives the cost of maintenance and some details of repairs to cookers for one year ended December 31, 1913.

The shrinkage of meat during electric cooking is about 10 per cent, compared with 25 to 40 per cent for gas and coal.* This feature is the result of subjecting the meat to an even temperature, which sears it and prevents the escape of juice. As practically no ventilation is required in an electric cooker, no air rushes through the oven, carrying away with it the cooking fumes. This feature also has the effect of preventing loss of weight.

The best type of utensils to use are those made of cast iron, with a turned or machined bottom. They do not buckle or burn the food when in use, are practically indestructible, and are better in all respects.

TABLE 5.

Type of Cooker	No. of Cookers	Total Cost of Repairs	Average Cost per Cooker	Details of Failures: Hot-plate Elements	Grill Elements	Oven Elements	Wiring Faults	Hot-plate and Grill Terminals	Miscellaneous Causes	Total No. of Faults	Remarks
		£ s. d.	s. d.								
"A"	4	1 6	$4\frac{1}{2}$	—	—	—	1	—		1	Apparatus in use 15 months only
"B"	41	18 2 7	8 10	52	44	18	13	8	10	145	Apparatus in use 2 years
"C"	25	23 0 0	18 $5\frac{1}{2}$	19 Duplex 18 Extensions	—	—	15	—	2	54	Apparatus in use 2 years

It is to the advantage of every one concerned that there should be as little wiring as possible about the cooker. Any wiring that must be placed on the cooker should be kept as far as possible away from the heat. Special attention must also be given to all connections that are in proximity to hot-plates, in order that any liquids that boil over may not affect them. The practice of employing beads for insulating purposes should be avoided. They become dislodged during transit and very often result in an "earth" or short-circuit. Asbestos-covered wire is satisfactory, but care must be taken to keep it away from moisture. The wiring on the cooker should be of nickel to avoid corrosion.

A separate control board should be fixed to the wall adjacent to the cooker and from 4 ft. 6 in. to 5 ft. from the floor. The connecting wires should be run in a flexible metallic tube. It is better to supply a separate switch and fuse for each section of the cooker, and each switch should indicate what section of the hot-plate or oven is in use. Indicating lamps are also desirable. It is advisable to connect the lamps so that they show a dull light when the elements are at a low temperature, and so that they burn brightly when the elements are at high temperature. When tracing faults this is also a ready means of ascertaining if the element is continuous. The outfit should be controlled by a double-pole ironclad switch and two single-pole fuses of the non-arcing type. It is essential that every precaution should be taken against the possibility of the cook receiving a shock. If this should unfortunately happen, it is likely to be difficult to persuade her to use the cooker again. The necessity of efficient earthing is obvious.

Periodical visits should be made to ensure that the consumer is getting the best results from the cooker, and hints should be given him as to how to use the cooker to the best advantage. An engineer is necessary for technical details, but a lady is more able to advise on culinary difficulties.

In Fig. 7 a number of typical curves are given showing when the load comes on at various consumers' premises, and how the peak compares with that of the system. The consumers' curves are given in amperes, while the curve for the entire supply system is given in thousands of kilowatts.

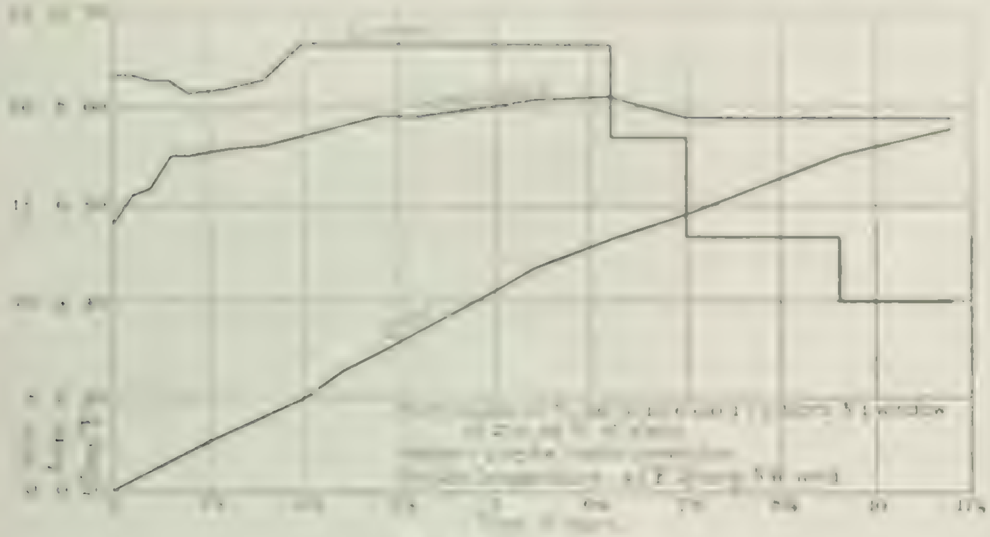
The dotted curve shows the summation of the consumers' loads, as compared with the load on the system.

HEATING.

Until quite recently electricity for heating purposes was considered a luxury, and it was only used occasionally or for special purposes, but owing to the general reduction in the price of electrical energy and improvements in the design of heaters, radiators and convectors have come into general use, and in some cases are used exclusively in preference to other methods of room heating. The convenience of electric heaters cannot be equalled by either coal, gas, or steam. The advantage of being able to place the heater in any part of the room, and the ability to

* This subject was very clearly dealt with by Mr. F. S. Grogan in his lecture before the Wolverhampton & District Engineering Society at Wolverhampton. *Electrician*, vol. 72, p. 864. 1914.

[illegible]



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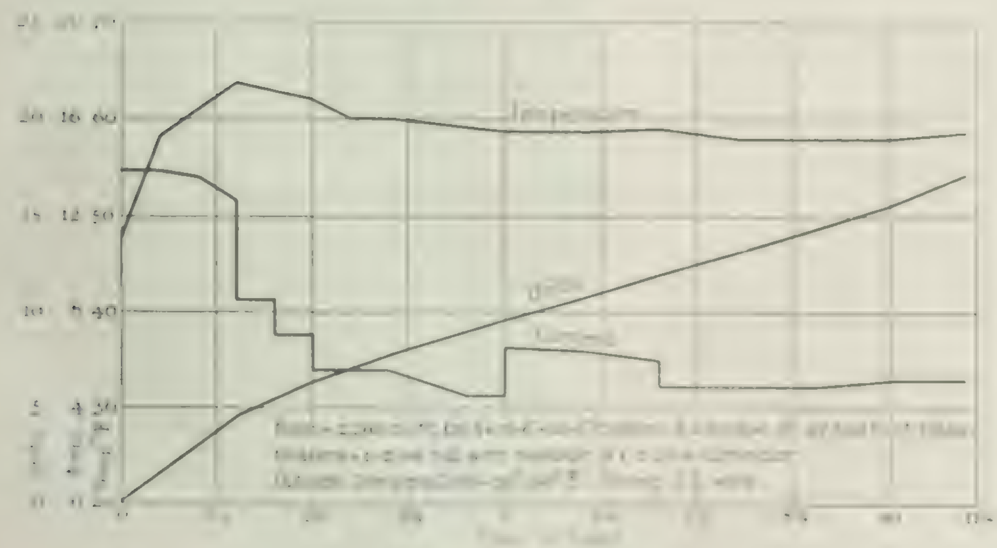


[illegible]

[illegible] required to overcome the losses due to leakage through doors, walls, etc.

[illegible] This figure should not be reduced unless very favourable conditions prevail. The author in most cases recommends [illegible]

[illegible] hours to raise the [illegible] F. in the first case, whereas in the [illegible] with the larger loading, the temperature was [illegible] F. in one hour, and up to 63° F. in $1\frac{1}{2}$ hours. It is interesting to note that the consumption over a similar period, viz. 11 hours, on the lower loading was 18·9 units, against 17·25. This proves that it is more economical to install a large heater. The conditions under the latter test were more severe than in the former, the outside temperature ranging from 36° to 40° F., and a strong S.E. wind blowing.

The question whether to adopt radiant or convected heat will depend entirely upon the local conditions. Convected heat is better for long-hour use, and in places such as halls or passages, where a heater is required to raise the temperature of the staircases and landings, a convector placed in the hall will assist considerably in warming the whole house. The warmed air passing through the passages will also assist the radiators in the various rooms. In bedrooms, where immediate heat is required, lamp radiators are very useful. Better results will be given if a suitable reflector is fixed behind the lamps. For intermittent use this class of radiator can be recommended. It gives a cheerful glow and at once warms anybody near it. The greatest drawback when using lamp radiators is the expense of renewals to lampholders and switches. The poor contact that is usually provided causes arcing across the plungers and switch contacts, which very soon destroys continuity. The author has found the cost of such repairs to be more than the cost of lamp renewals, probably because lamps connected two in series are employed in preference to lamps in parallel.

A heater designed to give both radiant and convected heat is undoubtedly the best type to use for general domestic requirements. These heaters usually consist of an ordinary lamp radiator with heating elements fixed at the back, each section being separately controlled. The convector portion is loaded to $1\frac{1}{2}$ kw. and the lamps to 1 kw. When running at its full capacity this provides a useful heater, and either section or both can be used according to requirements.

Another form of heater is a type where nichrome or similar non-oxidizing wire is employed and run at a temperature of 1,000° to 1,050° F. The wire is either wound on fireclay bars or in quartz tubes, which glow at a dull red heat. The metal portion of the heater gets hot and provides convected heat. A wire guard is fixed in front of the elements to prevent clothes or paper becoming ignited due to accidental contact. A heater of similar design, but with a quartz disc fitted over the element, is an excellent type for use in the bathroom as it is not damaged if splashed with water. This radiator should most certainly be efficiently earthed.

The position of a radiator in the room should be such that the heat given off must travel the longest distance before it can escape to the outside atmosphere. It should be insisted that heaters should not be placed in the fireplace. It is advisable to install heaters with a view to providing an even temperature. It will be found that if a large heater is placed in the fireplace, a cold draught of air will be felt at the floor level. It is much better to place two small convectors at opposite ends of the room, or where the cold air enters, and have a radiator near where persons are sitting. This method will prevent uncomfortable draughts and will give as nearly as possible an even temperature, but it will cost more to install, although the running costs will be unaffected. The extra comfort, however, is well worth the additional expense of the installation.

It is an accepted fact that electric heaters do not vitiate the atmosphere. They do, however, affect it in various ways. If too much convected heat is employed it will make the air stuffy, or if nothing but radiant heat is used it will dry the air; also, if high-temperature convector elements are employed they will have a tendency to "burn the air." Very good results will be obtained if low-temperature convectors are used in conjunction with a radiator, and no unpleasantness will be experienced with the atmosphere in the room. Where convectors are to be installed, preference should be given to those with sufficient perforation to allow free egress of air. If a few holes only are provided the convector case will get very hot, "heat locks" will result, and the life of the element will be shortened.

The general tendency is to install heaters of 2–3 kw. capacity to replace the earlier type of radiator of 1 kw. capacity. On old installations the switches should be carefully inspected to see whether they will satisfactorily open-circuit this load. For radiators of this size it is difficult to get small switches that can be fixed in the rooms without being an eyesore. The rotary type of switch is no doubt the best for breaking currents of 10 to 12 amperes; and wherever possible this type should be fixed. Plugs also call for attention. They should be of ample size, and the plug top should not be made of china, as these are continually breaking and causing inconvenience.

Electricity is used exclusively for cooking purposes in the author's own home, four adults and two boys being catered for, and the heating is carried out mainly by radiators and radio-convectors. Coal is only used for warming the kitchen and the boiler for hot water.

During 1913 the consumption for cooking was 2,129 units, heating 2,130 units, and lighting 370 units (this includes all current used for ironing).

With regard to meat shrinkage, in the author's own case it has been proved that with electrical energy at $\frac{3}{4}$d. per unit the saving on the shrinkage of meat pays for the energy consumed by the cooker.

The year's total cost of light and heat, assuming the electricity rates set out below, was as follows:—

	£	s.	d.
Fixed charge ($12\frac{1}{2}$ per cent of rateable value, £24)	3	0	0
4,629 units at $\frac{3}{4}$d.	14	9	4
	17	9	4
Less 5 per cent discount	0	17	6
	16	11	8
4 tons of coal (1 ton at 17s. 6d., 1 at 19s., and 2 at £1, plus 4s. carting)...	4	0	6
	£20	12	2

In conclusion, the author hopes that he has made it quite clear that electricity can be, and is, relied upon to carry out important requirements in ordinary households.

[illegible]

DISCUSSION.

[illegible] taken into consideration when discussing the length of [illegible] for the hot-plate curves (Figs. 4, 5, and 6). I will [illegible] type-C hot-plate, and would suggest that the steady temperature shown as about 500° F. is incorrect. [illegible] temperature of the type-C hot-plates taken by the National Physical Laboratory, and for the 800-watt plate the tem-[illegible] The temperature was taken at the ends of four different [illegible] surface was shown to be less than 0·75 per cent. Turning [illegible] so that the efficiencies shown are not as high as they ought to be. In fact, when water is boiled in a modern electric kettle efficiencies as high as 97 per cent can be obtained. Central station engineers should not pay too much attention to the hiring out and maintenance figures. There are many other considerations to take into account in fixing the hiring rate. Moreover, the figures given by the author are out of date. The curves in Fig. 7 show very clearly the diversity factor which has for years been claimed for the cooking load. Taking a diversity factor of 10, it means that instead of £10 about £1 per kilowatt is sufficient for the standing charges on cooking loads. In connection with Table 5 I would draw attention to the fact that with the type-C cooker only one-third of the hot-plates referred to are comparable with those in types A and B, because the average type-C equipment may be considered as consisting of three hot-plates, two of which are muffled up in [illegible] radiating surface, thereby increasing the life of the hot-[illegible] radiant heat is used, it will dry the air." Surely radiant [illegible] objects without heating the air except by indirect action. The ideal method of heating a room is that by which the air is kept at a low temperature, while the heat is transmitted to persons in the room by radiation directly from [illegible] walls and furniture.

[illegible] manufacturers have shown a tendency to standardize the ordinary type of gas cooker, but if he had looked more closely into the question I think he would have found that [illegible] seems to think that electric cookers should be nickel-plated, but I would much rather keep black parts clean than I would nickel-plated surfaces. Moreover, it is much more advantageous for a supply authority to adopt a black [illegible] considerable time it does not show the same deterioration [illegible] look like new at a very small cost, so that its chances of being hired out a second and third time are greater. The author discusses the rate of heating and cooling of ovens and arrives at the curious conclusion that an oven which heats up quickly also cools down quickly, irrespective of [illegible] To obtain a fair comparison, the ovens should have been [illegible] siderable time, presumably because it is more efficient: I [illegible] in the paper and find that cooker A comes first in heating with 2·2 watt-hours per cubic foot per degree rise in [illegible]

[illegible] and heating. *Journal I.E.E.* [illegible]

Mr. Crosbie. tively. The author is of opinion that rapidity of heating is of [illegible] today, but the consumer [illegible] gas and electricity bills, and [illegible] than gas to give up using his [illegible]. On the question of the thermometer I entirely disagree with the author. It is a most useful item. It does not matter whether the correct temperature inside the oven is given so long as the thermometer can be used as an indicator. By its help perfect uniformity in cooking results can be obtained repeatedly. Although I do not advocate a window and lamp, I might say that I have had a lamp in my oven at home for over 18 months and that it is apparently as good now as when I had the cooker installed. With reference to the radiant hot-plate which heats up 2 pints of water in 11 minutes, the author does not mention the loading. A Ferranti hot-plate on my cooker at home boiled 2 pints of water in 14 minutes for an expenditure of 170 watt-hours of energy, which is equal to an efficiency of over 64 per cent. I am in entire agreement with the author with reference to the heating element being evenly distributed over the heating surface, as there is no doubt that the failure of many hot-plates is due to uneven heating and cooling. A spiral element is the only one which ensures a perfectly even distribution of heat in a circular plate. In regard to the question of electrically heating rooms, under certain circumstances it is undoubtedly the best method of obtaining the maximum of comfort. When using a "Ferranti Fire" of 1,000 watts I recently found that the temperature of the whole room was raised much more rapidly than with a coal fire.

Mr. Pinkney. Mr. W. F. T. PINKNEY: It is curious that manufacturers should consider it necessary to make electric cookers on the same lines as gas cookers, for the public always takes an interest in something new. With regard to Fig. 7, can the author say whether the cooking peaks come on the main peak in the winter load? Another point of interest is: Do the cooking peaks come on the top of the lighting peaks apart from the station peaks? They would enter very largely into the question of mains.

Mr. Fawssett. Mr. E. FAWSSETT: I cannot agree with the figures on the curves for the hot-plates or with Table 3. In the case of the 8-in. hot-plate it means that the saucepan only utilizes about 50 per cent of the heat available. The important question with regard to the load curves in Fig. 7 is: How will the big cooking loads promised in the future affect the distributing mains?

Professor Stroud. Professor H. STROUD: The ideal method of heating a room is by radiation, because in this case the walls and objects in the room are first heated, and the air having a tendency to be cooler than the walls its relative humidity is thus not unduly lowered. I should also like to suggest to manufacturers the importance of standardization, particularly in regard to sizes of plugs, etc.

Mr. Hunter. Mr. P. V. HUNTER: The only point that I wish to discuss is the problem of heating a room. I think it is necessary to differentiate carefully in the functions of a heater between the duty required to bring a room to a comfortable condition and that required to maintain it comfortable. If given careful consideration, I think that electrical apparatus can yield results in this direction which are not readily possible in the case of either gas or coal. My suggestion is that a properly designed heater would warm up a room in a few minutes only, the rate of output during this initial period being several times that necessary to maintain the room at a comfortable temperature. Immediately after the initial period of warming up, a switch on the heater would be operated, thus reducing the rate of energy consumption to a fraction of that previously used. It is, I believe, a fact that a comparatively small electrical output is required to maintain a room comfortable once this condition has been established. Such an arrangement of heating would in my opinion have several important advantages. Not the least important of these is that consumers when once they experienced the convenience of such a heater would not fail to use it. It would enable them to use their living rooms more freely and at short notice without discomfort or adding to domestic labour. As the heavy demand by each heater would last a few minutes only, the diversity factor would be high and the load therefore profitable to the supply authority. It is of course necessary that the heater should be portable in order to keep the outlay for each house a minimum, and incidentally to increase the diversity factor.

Mr. Gillott. Mr. W. A. GILLOTT (*in reply*): In regard to the temperatures of hot-plate surfaces, Mr. Grogan in the first place overlooks that the tests recorded were obtained under ordinary working conditions, as mentioned in the paper, and then he compares the surface temperature of the hot-plate with the temperature of the inside of the plate. In connection with his remarks in regard to type-C cooker, Mr. Grogan must be aware that in Newcastle four hot-plates are supplied as a complete outfit.

In referring to radiant and convected heat in ovens, these terms were used in the broad sense, since everybody knows that it is impossible to have radiant heat without convected heat in some form or other. A quickly heated oven is to be preferred; it is ready for use much earlier, and, better still, it costs less to heat up. Both these points are appreciated by the consumer, and, after all, this is the person of most consequence.

In regard to the $5\frac{1}{2}$ in. saucepan used for water boiling, I must refer my critics to my statement that the tests were carried out under ordinary working conditions. A consumer cannot be expected to purchase utensils exactly to fit each hot-plate. The cook usually employs the first utensil that comes to hand, and does not select hot-plates by their size but by the quickness with which they boil liquids. Naturally, she uses the largest size. One knows very well that if utensils are used that exactly cover the hot-plate they will show a better efficiency, but such questions are overlooked in practice. The $5\frac{1}{2}$ in. pan was chosen because it is the average size of utensil used in household kitchens. The tests recorded are the results obtained by the consumers, and these are of real importance to the central station engineer. The efficiency of a self-contained utensil is admittedly as high as 97 per cent, but why should this figure be compared with that of a hot-plate under totally different conditions?

The maintenance figures given in the paper represent the actual facts in the Newcastle district and are quite up-to-date. It is absolutely necessary to obtain data of costs over one or two years in order to determine what is the minimum rental that can be charged. Apparatus that costs a lot to maintain will go out of use as being unsuitable and unremunerative.

With reference to Mr. Grogan's remarks on rooms

[illegible]

... warm a room as quickly as Mr. Hunter suggests. To [illegible] about 19/10 S.W.G. Moreover, owing to its weight such a heater could not be made portable.

PROCEEDINGS OF THE INSTITUTION

ORDINARY MEETING OF 29 OCTOBER 1914

Proceedings of the 560th Ordinary Meeting of the Institution of Electrical Engineers, held on Thursday, 29 October, 1914, Mr. W. Duddell, F.R.S., Past President, and Sir John Snell, President, successively in the chair.

The minutes of the Annual General Meeting held on [illegible] May, 1914, were taken as read, and confirmed.

The Chairman (Mr. W. Duddell) [illegible] Council in the place of the late Mr. A. B. [illegible] Association.

Donations to the *Library* were announced as having been received from The Anglo-Mexican Petroleum Company, Ltd., [illegible] Thompson, D.Sc., F.R.S., and H. P. Wiggins; to the *Museum* from W. Ellis; to the *Building Fund* from G. M. Robertson; and to the *Benevolent Fund* from T. H. Barr, S. E. Britton, The Electrical Engineers' Ball Committee, The General Electric Company, Ltd., [illegible] Meares, W. M. Morrison, A. Russell, D.Sc., S. A. Russell, C. W. Speirs, A. M. Taylor, and C. H. R. Thorn, to whom the thanks of the meeting were duly accorded.

The Chairman: I have also to announce that Mr. Evelyn Barnard has presented to the Institution a framed [illegible] Faraday [illegible] I think the Institution is to be congratulated on possessing such an extremely interesting historical [illegible], and I ask members to give a most hearty vote of thanks to Mr. Barnard for his presentation.

The vote of thanks was accorded by acclamation.

The Scholarships and Premiums referred to in the Annual Report of the Council * for the year 1913–14 were then presented by the Chairman.

Mr. Llewellyn Preece: I will not now detain the meeting for more than a few minutes, but I have a duty to perform which, though grievous from one point of view, mainly gives me much pleasure. About two and a half years ago my father made his last public appearance and his last speech. It was in this hall, before this Institution, and the occasion was, as most of you will remember, when he, on behalf of Lady Kelvin, presented to the Institution that beautiful bust of the great Lord Kelvin which now adorns our entrance hall. In his speech † my father coupled Lord Kelvin with Faraday and Newton as the principal founders of practical science. This remark led him to express the wish to see a bust of Faraday as a companion to that of Lord Kelvin, and he there and then promised that, if he was spared, he himself would present the Institution with this additional bust. My father never forgot to acknowledge his deepest gratitude to, and admiration for, these two great scientists. He revered them both as his honoured masters, and always held them up, not only to his sons but to all young men with whom he came in contact, as the highest embodiment of the true scientific spirit. It was to Faraday that my father owed his earliest instruction in electricity, first as a listener at his Royal Institution lectures, and later on—a fact of which he was more proud than of any subsequent honour—as an assistant in his laboratory. In truth, Faraday was the actual founder of my father's electrical career. Unhappily my father was not spared to fulfil his promise. He had but just got into touch with the eminent sculptor, Mr. G. D. Macdougald, when that High Power, whom all must obey, took him from us. It therefore fell to the children to complete the promise made by their parent. Mr. Macdougald went on with his work, and finished the splendid bust which we have in this building to-night. I should like to add that our deep gratitude is due not only to Mr. Macdougald for his excellent work, but to Professor Silvanus Thompson also for the speaking likeness presented to us. None of my brothers or myself had any personal recollection of the great philosopher, and we were therefore quite incompetent to help Mr. Macdougald. Professor Thompson, however, most kindly stepped into the breach; he paid many visits to the studio, and I am sure Mr. Macdougald would acknowledge that it is largely due to the efforts of Professor Thompson that the bust shows us the true features of Faraday. Mr. President, I now ask you, in the names of my sisters, my brothers, and myself, to accept for the Institution the admirable representation in marble now in the hall of the man whom we all acclaim to be the founder of the electrical profession and the electrical industry, the one man who is worthy to rank with Lord Kelvin. The bust will also, I hope, be considered a memorial of Sir William Preece, who was a personal friend of both, a pupil of both, who loved them both as true men, and who also in his time did much for our profession and this Institution.

The Chairman (Mr. W. Duddell): To Mr. Llewellyn Preece and to the members of the Preece family, we, as an Institution, tender our most hearty thanks for this very beautiful gift that has been made to us. The late Sir William Preece, who, as Mr. Llewellyn Preece has said, was one of the most enthusiastic promoters and supporters of this Institution, stated in this room that he hoped each of the two pedestals in the hall would be occupied by a bust. His words were: "An important question will arise, which we, of course, will leave in the hands of the President and Council, and that is the position of this bust"—he was then speaking of the Kelvin bust—"and, I hope, its companion"—the bust that is here to-night. "It has almost been solved for us, because you find on each side of this table"—the table at which I am speaking—"the name of Kelvin and the name of Faraday." He then explained that there was a difficulty in putting the busts in this room, and continued: "The very fine, handsome marble hall we have—there are two pedestals planted there evidently with the idea of supporting our two greatest heroes. Here they are, Faraday and Kelvin." To-night we have Faraday with us, thanks to the generosity of the Preece family. That Sir William had this subject at his very heart will be realized if I read a few words that he wrote to me during his long illness on the subject of this bust. In April of last year he wrote to me as follows: "It is now very nearly twelve months since the Kelvin bust was received by the Institution! I have not forgotten my promise to supply a bust of Faraday to match with it. I am only waiting to return to town to put the whole thing in operation." In October, when he was in Wales, in bed, he wrote to me again: "My doctor wants me to go to Egypt, and I have provisionally taken berths in the P. & O. *Mooltan*, which leaves Tilbury on November 14th. I have done nothing more about the bust of Faraday, but I will at once communicate with the sculptor who was to make the bust from the original statue at the Royal Institution, and give him orders to put it in hand. This will mean that I shall not be able to present it personally until I return from Egypt next April"—

* *Journal I.E.E.*, vol. 52, p. 632, 1914. † *Ibid.*, vol. 49, p. 698, 1912.

that in April of this year: "I will let you know exactly the arrangements I have made." Again in October of last year, he wrote: "I shall have to spend two or three days in London before I start, and I will certainly come and see you and talk over I.E.E. matters." Then, realizing that he was most seriously ill, he asked the Institution to appoint a Committee to see to the fund being made. The Committee was appointed, but, as events turned out, it never met. I think we have to thank once again the Preece family for carrying out what all of us know was so keenly the wish of the late Sir William Preece.

I now come to the last act of my presidency, and that is to present to the meeting my successor, Sir John Snell; I think I need scarcely introduce him. For the past eight years Sir John has been with us in London, and during the whole of that time he has constantly attended our meetings; he has also diligently served on the Council and has worked hard for the welfare of the Institution. Before he came to us in London he was Chairman of the Newcastle Local Section, and his knowledge of local affairs has materially assisted us in our work and deliberations. In his early life Sir John was an assistant to the late General Webber, who took such interest in the welfare of this Institution; and I hope and believe that the cloak of General Webber, so far as good wishes for the Institution are concerned, has fallen on my successor, Sir John Snell. Gentlemen, I present to you my successor, Sir John Snell.

The Chair was then vacated by Mr. DUDDELL and taken, amid hearty cheering, by Sir JOHN SNELL.

Dr. SILVANUS P. THOMPSON: It is one of the responsibilities or, shall I say, the privileges of increasing seniority, that I find myself in the capacity of senior Past President now in this room rising to propose: "That the best thanks of the members of the Institution of Electrical Engineers be given to Mr. William Duddell for the very able manner in which he has filled the office of President during the past two years." There are, happily, older Past Presidents than myself still alive and with us, but we miss their faces to-night, and, in the absence of those who are really my seniors, I have much pleasure in proposing this resolution. Anybody who has had the high privilege of filling the chair of this Institution knows not only that it is no light business to carry through the work of the presidency, but also that there is no institution in the world where the man in the chair will be more thoroughly, unitedly, and enthusiastically supported in his duties than is the President for the time being of the Institution of Electrical Engineers. With Dr. Ferranti to make the running for him, Mr. Duddell has fulfilled the duties of the office not, as was the custom previously, for one year, but for two successive years, and I venture to say that when the annals of this Institution are written in future time there will be no more prosperous two years recorded than those during which Mr. Duddell has guided our ship. Our Institution has gone through many changes from its primitive beginning, when the late General Webber and the late Sir William Preece were the active young men who pushed it into existence; but here we are, at the end of nearly 40 years, a thriving Institution of surprisingly rapid growth. When Mr. Duddell assumed office as President in May, 1912, the membership had already risen to 6,537, and during the two years of his presidency that number has been increased by over 500, our total membership at the corresponding period this year being 7,045, figures which speak for themselves. Not only have we had the benefit of Mr. Duddell's services in the administration of this Institution—he has been remarkably active, giving the best of himself unstintingly to the service of the Institution; he has been constantly in and out, looking after the welfare of the Institution, serving on various Committees, and dealing with the provincial membership by visiting the local sections—but he has left as a record in the pages of our *Journal* the Presidential Address which he gave when he entered on the first year of his office, and the very remarkable lecture and demonstration on "Pressure Rises," which those of us who were present will never forget and which is printed as the first article in our enlarged volume of the *Journal*.* The very least that we can do is to acknowledge the great indebtedness which we all owe, and the Institution owes, to Mr. Duddell for his efforts in so many directions as President of this Institution, and I therefore ask you to accord him our best thanks.

Dr. G. KAPP: Dr. Thompson had the privilege of proposing the vote of thanks because he is the oldest Past President present. I have the privilege of seconding that resolution because I am the youngest—not in years, but in office. I do not wish to take up the time of the meeting, so shall merely emphasize what Dr. Thompson said with regard to the high standing which the Institution has attained under the presidency of Mr. Duddell. We have in Mr. Duddell a pioneer in science, but at the same time a most practical and clear-headed man of business when it comes to furthering the interests of our Institution. Those of us who have been on the Council during his presidency know how hard he has worked, and I feel sure that having seen the increasing prosperity of the Institution you will be fully in accord with me when I ask you to pass a hearty vote of thanks to him.

* *Journal I.E.E.*, vol. 52, p. 1, 1914.

The resolution was put and carried with acclamation.

Mr. W. Duddell, F.R.S.: I thank you from the bottom of my heart for the way you have accepted this resolution. I have only done my duty to the Institution, and I hope in the future I may be able to continue to do so. I should like to say that the Council has continually supported me in trying to make this Institution a greater success than ever.

The President then delivered his Inaugural Address (see page 1).

Mr. W. M. Mordey: Dr. Thompson and Dr. Kapp have sped the parting President: it is my pleasant duty to-night in a few words on your behalf to welcome the coming President. When one thinks of it, he could not help becoming President of this Institution. He was educated at King's College and at Finsbury Technical College. At King's College Grylls Adams and John Hopkinson, two of our Past Presidents, were successively the Professors of Electrical Engineering; and we know what Finsbury Technical College owes to another Past President, Dr. Thompson. His engineering training was under Colonel Crompton and under General Webber, both Past Presidents, and he is now associated with the work begun by Sir William Preece, still another Past President of this Institution. Is it any wonder then, with all these advantages in his education, that he should be President here, and that we should be welcoming him in that capacity to-night? Then we come to his practical experience. He had ten years of practical engineering work and administration of a large electrical enterprise in the north of England, and in spite of all the labours of that position he showed his energy and his public spirit by taking a prominent part in the work of the Institution through its Local Section at Newcastle. For some years he was on the Committee of that Section, and he was the Chairman in 1901. Then he came to London, where he has been for eight years, going rapidly up the ladder all the time. He joined the Council in 1908, became a Vice-President in 1911, and we elected him President this year, and shortly after that we had confirmation of the wisdom of our choice when he was knighted as a reward for services in connection with a great national undertaking, the nature of which I need not allude to now. I am sure members will all agree with me that he thoroughly deserves his rapid success, not only as an authority on engineering as such, but also on the business, financial, and accountancy side of engineering. With such an equipment and such an experience I am sure the Institution has been wise in electing him to the position which he now occupies. He has given us to-night an address which is distinguished by the qualities for which we were prepared—it is able, clear, practical, useful, and interesting. He has given us much over which we shall ponder. For these reasons I have very great pleasure in proposing: "That the best thanks of the Institution be accorded to Sir John Snell for his interesting and instructive Presidential Address, and that with his permission the Address be printed in the *Journal* of the Institution."

Mr. C. H. Wordingham: It is with the keenest pleasure that I rise to second the resolution that Mr. Mordey has just proposed, not only because I like to see the chair filled by so able a man, but because of the long friendship that Sir John Snell and I have had. We have been together on this Council for a long time, but I refer more especially to the old days of the Municipal Electrical Association, or rather the Incorporated Municipal Electrical Association as it now is, and it is pleasant to see that the sterling worth which I know so well Sir John Snell possesses has met with this fitting recognition. I should also like to add to what Mr. Mordey has said, and express my appreciation of the address to which we have just listened. Sir John Snell's opinions are always sound and practical; he is not carried away by extremes. Perhaps I think his opinions are sound because I nearly always find they are the same as my own!

The resolution was carried by acclamation.

The President: I thank the proposer and seconder of this resolution very much for the kind words which they have said, and also the members for their kind support of it. I also appreciate very much the way in which this, I am afraid very prosy, address has been received, and I am sorry for having taken longer in delivering it than I intended.

The meeting adjourned at 9.47 p.m.

THE JOURNAL OF

The Institution of Electrical Engineers

Vol. 53. 15 DECEMBER, 1914. No. 238.

CABLES.

By C. J. BEAVER, Member.

[illegible]

SUMMARY.

[illegible]

Electrostatic effects in high-voltage cable practice.

[illegible]

[illegible] cables.

[illegible]

(1) [illegible] and chemical properties of component parts of the [illegible]

(a) [illegible] "overdrying" paper and the attainment of high insulation-resistance values.

(b) [illegible] method of application to the cable.

(2) Conditions external to the cable.

(a) Troubles due to overloading. Expansion and contraction effects.

(b) Temperature rise of cables.

[illegible]

Rubber-insulated cables.

(1) Physical and chemical properties of component parts of the cable.

(2) Conditions external to the cable.

(a) Deterioration due to natural causes.

(b) Deterioration due to external influences.

(c) [illegible] tinning of copper conductors. Influence of technical operations on the harmful and the innocuous factors in the case.

Vulcanized bitumen cables.

[illegible] temperature.

[illegible] negative cables.

[illegible]

(g) Experimental reproduction of the second type of softening.

(h) [illegible] type of softening.

[illegible]

INTRODUCTION.

[illegible]

Mr. O'Gorman's masterly development of those ideas, and the practical suggestions which he based thereon in his paper presented to the Institution in 1901,* marked the transition from the rule-of-thumb to the scientific stage of cable manufacture. That those suggestions have not yet come to fruition is partly due to economic and commercial reasons, and partly to the fact that the necessity for adopting them or similar measures is only now becoming acute. It is certain that if such a general advancement in working pressures had been made as to necessitate the use of, say, 100-kilovolt insulated cables, the grading of dielectrics in some form or other would have become essential before now. Pressures up to 20 kilovolts have called for no special effort on the part of the cable maker, nor have they brought him face to face with the commercial proposition of greatly complicating his manufacturing processes in order to keep the dimensions of his cables within the limits of ordinary installation practice.

True, he has had to pay more attention to potential gradients in 20-kilovolt to 30-kilovolt cables than in those already standardized by the Engineering Standards Committee for working pressures up to 11 kilovolts, partly for the reason that there is greater competition for unstandardized cable, and partly because the test voltages of 50–100 kilovolts called for at these higher working pressures entailed stresses in the dielectric which approached the dielectric strength of his materials.

In cables for voltages up to 11 kilovolts the maximum stresses were quite low, as was pointed out by Dr. Russell.† This was partly necessitated by mechanical considerations, partly by cable manufacturing conditions, and partly by difficulties in the way of standardizing complicated forms of cable (such as those having hollow conductors), and was partly entailed as a relic from the rule-of-thumb days of cable making. At 6 to 11 kilovolts the opportunity for redesigning dielectric thicknesses was apparent years ago, when manufacturing practice was brought from the dark regions of chance and mystery to the light of scientific knowledge, because at the standard thicknesses employed for such voltages the mechanical and manufacturing considerations to some extent disappeared; but apparently nobody had the courage or opportunity to take the step of reversing the practice of increasing the thickness of the dielectric as the size of the conductors increased.

The importance of this, however, disappears at higher voltages. For instance, at 20-kilovolt working pressure the commercial considerations which entail the selection of such a voltage also to some extent automatically determine the most commercially economical (from the transmission and distribution point of view) size of cable. This will not vary widely from 0·1 sq. in. to 0·15 sq. in.

Construction of Conductors for High-voltage Cables.

At still higher working pressures, 50 to 100 kilovolts, another set of conditions preponderates, the maximum-stress conditions tending to fix a size of conductor on account of considerations of the economical construction of the cable—that is to say, a cable required for these working pressures has, in order to keep dielectric thicknesses within practicable limits, to be designed so that the conductor radius, r, is proportioned to the maximum stress permissible in the dielectric, according to the formula $r = V/S$, where V is the working voltage, and S the maximum stress permitted in the dielectric. It is at these working pressures, therefore, that the factors of character and curvature of conductor surface, and dielectric properties of the insulating material, become of paramount importance, and that any grading device which will tend to keep down the potential gradient must and will be eagerly sought after.

Let us first consider the curvature and character of the conductor surface. With regard to curvature, it is obvious that a large current-carrying capacity will not be required in such high-voltage cables, and the large radius desirable from the point of view of keeping the maximum stress within economically permissible limits is directly opposed to this. Conductors would therefore invariably be made in hollow form to a radius determined by the above-mentioned formula.

The most economical radius of conductor for a given working voltage at a given maximum stress is shown in

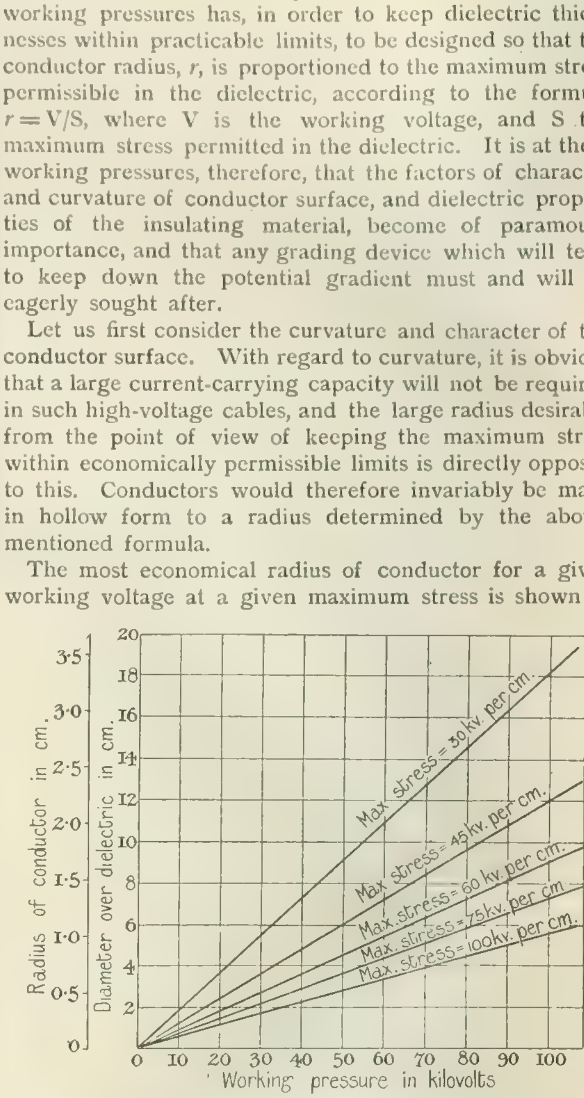


Fig. 1.

Fig. 1. The scale of "diameter over dielectric" refers to single cable. As the radius of conductor, r, is the most economical for each condition of working voltage and maximum stress, the radius, R, over the dielectric is equal to $r\epsilon$, where ϵ is the base of Napierian logarithms, $= 2·718$.

Fig. 2 shows a further aspect, *i.e.* the bearing of the radius of the conductor on the breakdown pressure for given thicknesses of dielectric, assuming 200 kilovolts per cm. to be the maximum stress that the dielectric is capable of supporting.

With regard to the character of the surface of the conductor, many references have been made in the literature of the subject to the proposal, first made the author thinks by Dr. Borel, to "lead sheath" the conductor. The credit for the suggestion lay in the appreciation of the necessity for the sheath. Given this, the proposal in principle was rather an elementary and obvious one, such as any electrical engineer might naturally have suggested to overcome a difficulty due to the concentration of electric stress on any

* M. O'Gorman. Insulation of cables. *Journal I.E.E.*, vol. 30, p. 608, 1901.

† A. Russell. The dielectric strength of insulating materials and the grading of cables. *Journal I.E.E.*, vol. 40, p. 6, 1907.

[illegible]

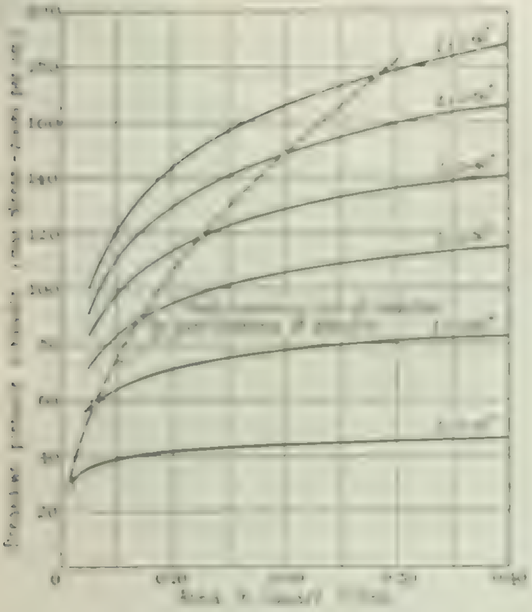


FIG. 2.

is well known, used this lead-sheathing method in his graded cable and calculated that by doing so he obtained a reduction of [illegible] per cent in the maximum [illegible] the innermost part of the dielectric.*

From the point of view of practical construction, it will be seen that the essentials for very high-pressure cables are a large conductor radius, a smooth surface, and true cylindrical form. To secure the latter, the author proposes to form the hollow core of a substantial lead tube.† The other conditions are complied with by stranding the necessary number of copper wires upon the tube, and sheathing over them with a thin wall of lead.

Fig. 3 shows the dimensions of a conductor designed on

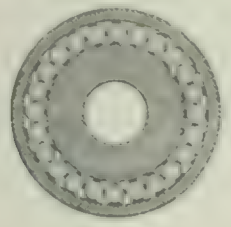


FIG. 3.

[illegible]

these lines for a 50-kilovolt cable, allowing for a maximum stress in the dielectric of 50 (R.M.S.) kilovolts per cm.

* A. Russell. *Loc. cit.* † Patent No. [illegible]

Fig. 4, [illegible]

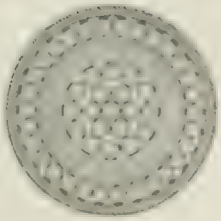


FIG. 4.

[illegible]

[illegible] increase in the overall dimensions of the cable.

[illegible]

Turning to the matter of dielectric properties, the ques- [illegible] order to obtain a series of capacities of the required values are practicable from the cable-manufacturing point of view. [illegible] culties attendant on his proposed method of using paper impregnated with compounds of varying composition, and noted that the widely used method of impregnating paper cables after the paper was applied to the conductor gave "inverse" grading effects. The author is not aware that [illegible] ing degree to obtain varying specific inductive capacities was ever put to a practical test, but in the light of present- [illegible] ciable reduction in dielectric strength would accompany the increase in capacity thus obtained, and also that [illegible]

[illegible] fering with their dielectric strength or impregnation, the difference between linen, manila, jute, and wood-pulp papers due to their composition and structure being appreciable. It is doubtful, however, whether sufficient variation could be obtained for the purpose by this [illegible] impregnating compound at the same time.

[illegible] adjustment of the capacity by loading the layers of vulcanized rubber must affect the dielectric strength and therefore limit the breakdown value of the dielectric to that of the layer having the highest specific inductive capacity. The permanence of such a cable, unless a large factor of safety were adopted in its design, would probably [illegible] because the natural rate of deterioration of vulcanized rubber is greater than that of [illegible]

* [illegible]

the close contact and probable diffusion of the impregnating material of the paper layers into the rubber would also be a factor in shortening its life and altering its dielectric properties, especially if the impregnating material was of a resinous character.

(a) *Inter-sheath grading* v. *capacity grading.*—From the cable-manufacturing point of view the simplest and most reliable method of grading is by what may be described as the intermediate-sheath method of potential distribution, which consists of the interposition of metallic layers in the wall of the dielectric and of "anchoring" them at suitable predetermined potentials. As regards the construction of the cable, this method relieves the situation from manufacturing complications because it is much easier to ensure a high and uniform standard of dielectric strength than to control suitable capacity grading.

In the discussion on Dr. Russell's paper Mr. C. P. Sparks said, "First of all, there is great practical difficulty in the grading of cables, owing to the fact that insulating materials have different chemical properties. The user of cables has to look at the matter, not from the point of view of a few years' life, but as a question of cables lasting for long periods, 25 or 30 years being a reasonably low limit of life. Hence I have no wish to use cables constructed with more than one kind of insulating material."

The majority of large cable users would probably have the same general feeling in the matter, and would be more inclined to adhere to the use of a single dielectric material with a fully proved history as regards durability, than to a combination of materials. Another practical point of vital interest to large users would be the question of jointing, which would obviously be much more difficult in cables graded by varying materials than in cables having a single dielectric material graded by intermediate sheaths. An incidental advantage of this type of grading is that the electrostatic discontinuity difficulty referred to by Osborne in his paper on "Potential Stresses,"* and which is liable to occur between layers of material of different specific inductive capacities, is minimized.

In the author's opinion the effect of the consequent distortion of the electrostatic field due to imperfect contacts between conductors and dielectrics is of such practical importance that he has proposed † to use metallized paper layers—the metal coating being next to the conductors—in order to minimize such effects.

The author prefers the inter-sheaths to be in the form of a lead tube, which enables a close fit to the dielectric to be uniformly maintained and presents smooth surfaces. In most cases the minimum practicable thicknesses of such sheaths will easily carry the charging current. This construction gives the important advantage, from the point of view of efficient manufacture, that the cable may be thoroughly tested after each intermediate sheath is applied, and also between sheaths in the completed state. It will be appreciated that this feature is a very satisfactory one from the purchaser's point of view also.

(b) *Methods of inter-sheath grading.*—Various methods of accomplishing the necessary distribution and anchoring of potential for both continuous-current and alternating-current cables have been patented by Tanner and Claremont.* One method, by adding suitable external capacities in the form of condensers connected between the potential-distributing sheaths, was patented by the Land and Sea Cable Company.†

Professor J. T. Morris in a communication on Dr. Russell's paper suggested ‡ inter-sheaths connected to transformer tapping points, but had not apparently gone beyond consideration of the bare principle, no reference being made to the relative spacing of the sheaths, the resultant distribution of potential, charging current requirements, and other essentials of design. An arrangement on similar lines applied to the windings of high-voltage machines was patented by the British Thomson-Houston Company in 1907.§

Another well-known instance of a somewhat similar type of grading is found in the condenser type of terminal now largely used in high-voltage transformers. In this case the capacities of the various layers (forming condensers) are adjustable by trimming back the tinfoil layers to the required extent, this adjustment being sufficient in such short conductors approximately to equalize the potential gradient.

According to the methods of Tanner and Claremont, the adjustment of its distribution and the anchoring of the potential in the case of alternating-current cables may be achieved by taking tappings from transformers at suitable points, or by using separate compensator or choking coils either across the mains or between the main conductors and the grading sheaths. In the case of continuous-current cables the proper distribution may be effected by taking tappings from generators at the desired potential points, or by adding suitable external resistances in parallel with the units of the dielectric.

The simplest of these methods entail the disadvantage, from the user's point of view, that they require modifications or additions to the apparatus to which they are connected, such as intermediate tapping terminals on transformers, generators, etc. The less simple methods involve the introduction of more or less special apparatus, such as compensators, choking coils, resistances, etc.

It is clear, therefore, that from the commercial aspect it is desirable to keep down the number of inter-sheaths, so that the saving on the cost of the cable due to the method of grading shall not be counterbalanced by the cost of modifications to the connected plant.

With this aspect in view it is interesting to take the concrete example of a 75-kilovolt alternating-current single cable and to examine the effect of using one or more potential distributing layers under given conditions of maximum stress, say 45 (R.M.S.) kilovolts per cm.

(c) *Comparisons in the case of 75-kilovolt single cables.*—In Fig. 5 the radii of the component parts are shown for cables having one and two inter-sheaths respectively. It will be noticed that the latter starts with an advantage as regards the "radius over the conductor," both being the most economical for the voltages across the first layers at the maximum stress chosen. This initial advantage is somewhat discounted by the radial thickness of the extra inter-sheath, the net result being that the total radius over

* H. S. OSBORNE. Potential stresses in dielectrics. *Transactions of the American Institute of Electrical Engineers*, vol. 29, p. 1553, 1910.
† Patent No. 19,882/1914.

* Patents No. 27,858/08 and No. 27,859/08.
† Patent No. 25,058/1905.
‡ *Journal I.E.E.*, vol. 40, p. 50, 1907.
§ Patent No. 25,834/1907.

[illegible] (¼ in.) [illegible] cable having two inter-sheaths than in the cable having one.

[illegible]

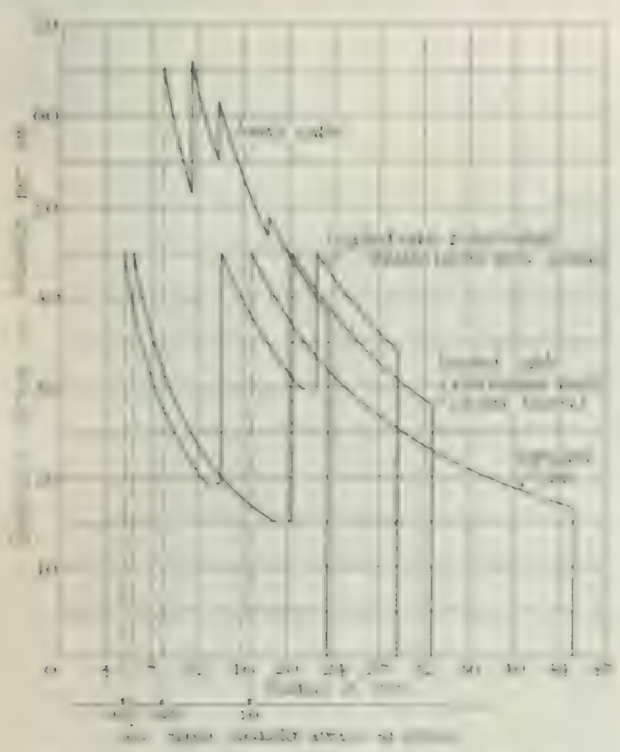


Fig. 5.—Cables for a Working Pressure of 75 Kilovolts.

of the inter-sheaths of $R/r = 5$, where R is the inner radius of the lead covering, and r is the outer radius of the conductor; and led to a division of the total radial thickness of the dielectric into two and three equal parts respectively for the cables with one and two inter-sheaths. When R/r is less than 5, the range of commercial usefulness of the inter-sheath method of grading begins to approach its limitations. Estimates of the cost of cables show that the lower limit of commercial advantage corresponds with working pressures in the neighbourhood of 50 kilovolts.

Fig. 5 was designed to show one or two other comparisons which may be of interest. The working pressure of 75 kilovolts was chosen because this would appear, from the maximum-stress point of view, to be the highest safe working pressure of the Jona cable previously referred to. This cable has been described frequently. The essential details for the present consideration are given in Dr. Russell's paper. The comparison between Jona's cable and the inter-sheath graded cables is of course only general, owing to the basis of design being different, but it serves to focus one's ideas on the effect of forcing the dielectric stress to high values and increasing the number of layers, against which one has to balance margins of safety, complications and difficulties of manufacture (entailing additional cost), and durability. The further com- [illegible]

[illegible]

[illegible] cables, it will be seen that taking into consideration the [illegible]

[illegible] The maximum stress in the dielectric at the working pressure is 52 kilovolts per cm. Details will be published at a later date. Fig. 6 shows a section of one of the single cables.

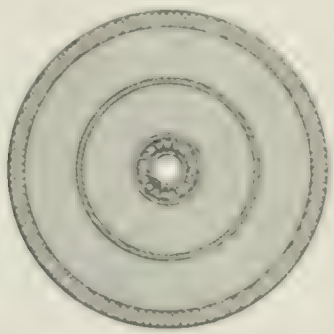


Fig. 6.

Conductor – [illegible]	[illegible]	[illegible]

MAXIMUM STRESSES IN HIGH-VOLTAGE PAPER CABLES.

In the commercial manufacture of paper-insulated cables a breakdown stress of about 200 kilovolts * per cm. may be regarded as the maximum obtainable in the present state of the industry. For purposes of guaranteed tests, an average safe figure of, say, 120 to 150 kilovolts per cm. may be taken as representing good practice.

The original design of a cable, however, has rather more direct reference to the test pressures than to the working pressure for which it is ultimately to be used; and therefore, as test pressures specified for 50- to 100-kilovolt cables [illegible] pressure, the maximum stress under working conditions will be 40 to 50 kilovolts per cm., or thereabouts. This is a fair practical working limit from another point of view [illegible]

* A. Russell [illegible]

* R.M.S. [illegible]

points of view from which such heating is undesirable in important e.h.t. transmission cables.

Fig. 7 gives a general idea of the effect on the diameters of cables of the permissible limits of maximum stresses.

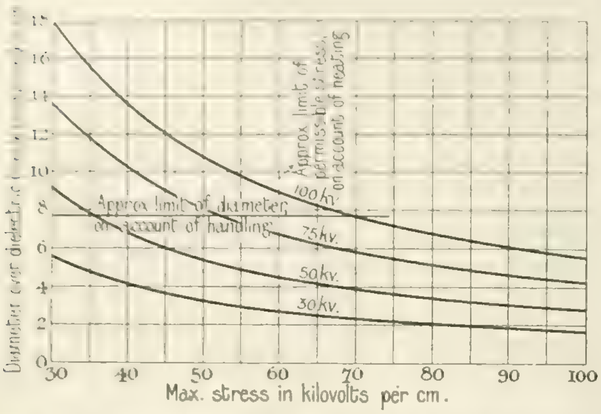


FIG. 7.—Diameters over the Dielectric of the most Economical Cables for given Working Pressures, at various Maximum Stresses.

The limit lines divide the diagram into three parts. The lower left-hand area represents conditions where stress and diameter conditions do not render grading absolutely essential. In the upper left-hand area the conditions render grading imperative. This area represents conditions which, as regards both electric transmission requirements and cable construction limits, may be considered to represent the present situation. It may be noted that the introduction of one inter-sheath serves the purpose of bringing a given cable from the upper to the lower left-hand section of the diagram.

The right-hand area in which the curves are less steep is interesting as representing the decreasing inducement to force up maximum stresses above 60 kilovolts per cm. in order to obtain economy in the diameter of the cable and therefore in its cost. The diagram shows that the limitations of the range of usefulness of grading arising from these practical considerations coincide with the commercial limitations previously referred to. The conditions which call for grading appear to be :—

(*a*) Working pressures exceeding 50 kilovolts.
(*b*) Maximum stresses above 60 kilovolts per cm.
(*c*) Where cable diameters would exceed, say, 3 in.

ELECTROSTATIC EFFECTS IN HIGH-VOLTAGE CABLE PRACTICE.

It cannot be too strongly emphasized that, as working pressures get higher and higher, electrostatic effects will be the most prolific source of trouble, and will accordingly have to receive the most minute attention. Reference has already been made to the effect of electrostatic discontinuity in a dielectric and the danger of local potential gradients thereby set up. Another source of trouble of similar character exists at cable ends, and the general principle of tapering off the electrostatic field has to be closely followed in practice in order to prevent deteriorating effects due to static discharges, such as the formation of ozone and oxides of nitrogen and the mechanical dispersion of impregnating media.

Fig. 8 shows a temporary method of dealing with this trouble during test periods in the cable factory.

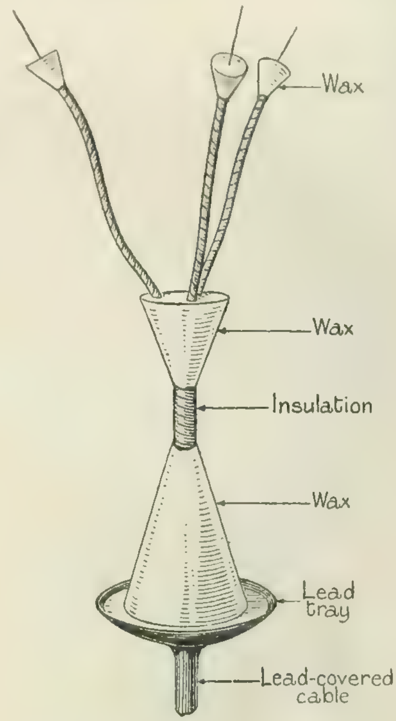


FIG. 8.

The lead sheath is carefully and uniformly expanded radially and a metal tray is soldered on to it. Wax is then poured into the tray and moulded around the dielectric as shown in the illustration. Similar wax moulds are applied where the cores of multicore cables separate, the discharge at the fork being sufficiently intense in some cases to ignite the paper worming used to pad the cores into circular form. At the ends of the cores similar wax mouldings are applied as shown. They give sufficiently good results for the temporary purpose of testing.

Reference is made later to the danger arising in joints on high-voltage cables from concentration of electrostatic stress in conjunction with weak paths. General experience, such as that which has been obtained with high-voltage generators, coincides with cable experience. Laminated insulation, coupled, it is true, with peculiar susceptibility of the insulating material,* has given trouble at pressures as low as four or five thousand volts, and has had to be abandoned, materials and methods of application and assembly being adopted which in effect aim purely at combating electrostatic trouble.

TESTING HIGH-VOLTAGE PAPER CABLES.

(*a*) *Electrical factors of safety.*—As regards the relation between test pressures and working pressures, the electrical factor of safety will of necessity be smaller on 50- to

* A. P. M. FLEMING and R. JOHNSON. Chemical action in the windings of high-voltage machines. *Journal I.E.E.*, vol. 47, p. 530, 1911.

[illegible] cables than on cables for lower pressures, for the [illegible] previously stated, which will [illegible] that the highest permissible [illegible] stresses be used. For instance, referring to "straight" tests on factory lengths of 20-kilovolt cable (not short lengths or [illegible] treated [illegible] or mechanically ill-used samples), an intensity of 2½ times the working pressure is found by experience to be a sufficiently high pressure to satisfy commercial purposes and practical experience. In [illegible] to 100-kilovolt cables constructed under higher maximum stress conditions, it will hardly be permissible for "straight" tests to exceed twice the working pressure.

Under other test conditions, now fairly well standardized for [illegible] cables, which [illegible] breakdown tests on lengths of a few yards cut from factory lengths, either left [illegible] or subjected to mechanical ill-usage [illegible] or to heating by immersion in boiling water, the breakdown pressure for [illegible] cables is [illegible] to be as high as [illegible] times the working pressure. For [illegible]-kilovolt cables this figure should hardly exceed, say, [illegible], and for [illegible]-kilovolt cables, say, [illegible] times the working pressure.

The following table gives an approximate idea of these [illegible] maximum pressures which under working conditions are [illegible] as far as [illegible] experience warrant, and under test conditions to a point which is likely to be the [illegible].

Working Pressure.	Maximum Stress at Working Pressure.	Test Pressure.		Maximum Stress under the Conditions of the Second Test.
		[illegible]	[illegible]	
[illegible]	[illegible] per cm.	[illegible] kv.	[illegible] kv.	[illegible] kv. per cm.
[illegible] ..	48	100 ..	125 ..	[illegible] .. .. ..
100 ..	[illegible]	200 ..	250 ..	[illegible] .. .. ..

(b) *Time element in pressure tests.*—The time element in these pressure tests is one that must not be forgotten, because it is a factor which assumes a considerable degree of importance where large thicknesses of dielectric are involved. English cable-practice has always been opposed to anything approaching the "flash test" which is made [illegible], and the dissection of a heavily insulated cable that has broken down under pressure cannot fail to impress on the observer the futility of anything less than, say, half an hour's application of any pressure designed to find weaknesses without overstraining a sound dielectric.

Cables sometimes break down under test near the expiration of the standard half-hour period, and as such breakdowns bear no relation to the dielectric strength of the insulating materials and cannot reasonably be supposed to be absolutely sudden and unpreceded by a development period (in fact, evidence of such development can almost invariably be found), the risk of interrupting the development in an incipient or early stage will be much greater in the case of a very thick dielectric. This is obviously an argument in favour of grading by intermediate sheaths.

In testing joints to destruction at pressures in the neighbourhood of [illegible] [illegible]

[illegible] happened that the [illegible] to [illegible] the breakdown [illegible]. These are of course exaggerated cases, because there is a [illegible].

(c) [illegible] with the testing of cables having large thicknesses of paper [illegible] yards of a low-tension cable will only be distributed among a few of the outer layers in a 500- or 600-mil dielectric, and its path of least resistance will be longitudinal rather than radial [illegible]. Under these conditions it is a matter of [illegible] sufficient amount to cause trouble when it has had time to [illegible] the lead covering.

To obviate this difficulty the author has suggested,* and [illegible] the lead covering to give an insulation resistance of the order of [illegible] megohms per mile. [illegible] between this sheath and the lead covering afford an absolutely reliable proof of the presence or absence of water so far as ingress through the lead sheath is concerned. The test sheath is also useful for maintenance tests, especially on subaqueous high-voltage power cables.

(d) [illegible] of heating and bending tests on the breakdown point of the dielectric of a paper-insulated cable, experience shows that the former, which usually takes the form of immersion in boiling water for half an hour, does not on the [illegible] appreciably reduce the breakdown voltage.

In the case of bending tests of ordinary severity it depends on the amount of displacement of the layers of paper under the effects of mechanical ill-usage, and is therefore to some extent dependent on the form of the cable—that is to say, the resistance it offers to [illegible] and the facility with which it can regain the [illegible] relative disposition of its component parts—and the thickness of the dielectric. An average reduction of the breakdown voltage due to these causes may be taken as 15 to 20 per cent for well-constructed e.h.t. cables.

(e) [illegible] testing point of view, to have [illegible] increase of the power factor with an increase of the test

* [illegible]

voltage. More recently Mr. Rayner described a method for arriving at a similar end by superposing a continuous current on the alternating test current, and showed that the values of the continuous current which could be passed through a dielectric under test rapidly increased as the point of failure was approached.

Höchstädter states, however, that breakdowns occur suddenly, and that from oscillographic records no change whatever takes place in the properties of the dielectric up to the point of breakdown.

It seems highly probable that the results obtained by the two first-mentioned authorities were due to the effect of temperature on the capacities of the dielectrics experimented on, and that these effects did not occur in the cables referred to by Höchstädter.†

In the course of his account of the research referred to, this author notes that the true capacity (by alternating-current methods) remained constant, and that the dielectric losses followed a steady curve up to the breakdown point without any change occurring in the properties of the cable. He does not claim that his results apply generally, but he thinks that much depends on the particular material under consideration.

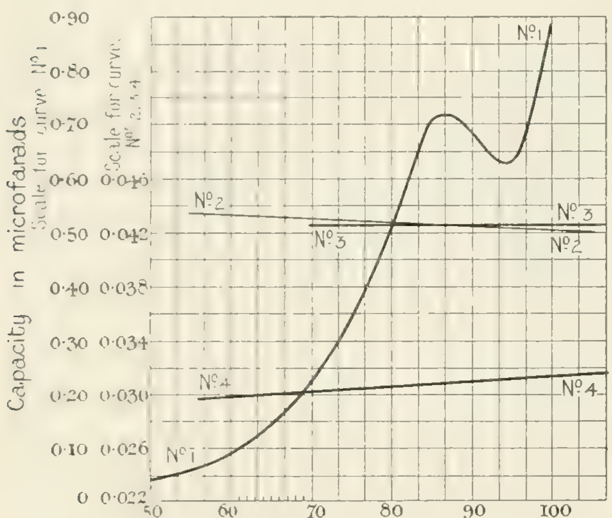


FIG. 9.

Fig. 9 shows the variation of capacity with temperature in the case of four different compounds, selected—as types—from a large number experimented on by the author. Curves 2 and 4 illustrate slight negative and positive temperature coefficients respectively, and Curve 3 an absence of temperature coefficient such as Höchstädter's results indicate for his material. Curve 1 is vastly different both as regards specific value at a given temperature and the value of the temperature coefficient. It also shows peculiar variations in the latter value at a critical temperature range.

The enormous differences shown to exist may possibly have some bearing on the divergence of views of the authorities referred to.

* *Journal I.E.E.*, vol. 49, p. 47, 1912; also vol. 52, p. 77, 1913.

† *Elektrotechnische Zeitschrift*, vol. 33, pp. 467, 509, 537, 558, and 570, 1912; also *Electrician*, vol. 65, p. 856, 1910.

In passing it may be of interest to note that the tests showed a more or less distinct relation between the physical properties of the compounds and the variations in the capacity. For instance, the compound to which Curve 1 refers (composed of mineral oils, waxes, and resin), and which obviously had not been adjusted for electrical purposes, was found to owe its peculiar variations between 85° F. and 98° F. to re-arrangement of the solution of some components in others.

Compound No. 2 was also a mixture of oils (resinous oils predominating, but mineral oils also present in small proportion), waxes, and resin, which had been carefully prepared and proportioned for cable purposes.

Compound No. 3 was a true solution (of resin in resin oil) at all temperatures, and Compound No. 4 a crystalline solid (mineral wax) of fairly definite chemical composition, having a melting-point of 132° F.

The compounds were tested by the ballistic method in a large condenser specially made for the purpose, consisting of a number of thin metal tubes arranged concentrically, temperatures being determined by measuring the resistance of fine wire coils wound on some of the tubes.

WORKING VICISSITUDES OF INSULATED CABLES.

Troubles which arise from working conditions may be considered from two general aspects, namely,

(1) Physical and chemical properties of the component parts of the cable.
(2) Conditions external to the cable.

In general, only three types of insulating material need be considered, namely, paper, rubber, and vulcanized bitumen.

PAPER-INSULATED CABLES.

(1) PHYSICAL AND CHEMICAL PROPERTIES OF COMPONENT PARTS OF THE CABLE.

The advantages due to the chemical stability of pure manila paper, and the durability resulting therefrom, are offset to some extent in practice by its hygroscopic properties, necessitating careful sealing wherever the dielectric is exposed. No degree of impregnation will render paper waterproof to the extent necessary to comply with the requirements of cables.

(*a*) *"Overdrying" paper and the attainment of high insulation-resistance values.*—In connection with impregnation, there are one or two erroneous impressions which require correction. One is that paper may be "overdried" during cable-making operations; and another is that high insulation resistance is obtained by overheating the dielectric, or in other words is due to manufacturing accidents or imperfections. Even now one occasionally sees modern specifications which state that cables having an insulation resistance of over —— megohms per mile will not be accepted.

With regard to the former fallacy, the author would repeat the statement which he made last year during the discussion on Mr. Evershed's paper,* to the effect that paper contains hygroscopic moisture which can be

* S. EVERSHED. Characteristics of insulation resistance. *Journal I.E.E.*, vol. 52, p. 51, 1913.

[illegible] Therefore, while paper may be overheated it cannot be overdried.

[illegible]

[illegible] accompany overheating or too prolonged heating, and [illegible] the matter kept alive in their minds. The point, however, is that high insulation does not necessarily indicate overheating. It depends, in a well-made paper cable, on the [illegible]

[illegible] of seconds, as compared with hours in other makes in which the paper is impregnated after application. Yet the dielectric in the former gives an appreciably higher insulation resistance than the latter, for reasons which relate solely to specific values for the materials used.

[illegible] It will be noted that the method of impregnating the paper before the latter is applied to the cable not only renders overheating impossible, but ensures the maximum degree of uniformity in manufacture, and consequently in the electrical properties of the cable. Such uniformity has long been recognized to be of considerable moment.*

It is also important that under working conditions, into which heating of the dielectric will almost invariably enter, the impregnating medium should remain in its original position throughout the life of the cable. For these reasons the author prefers to impregnate the paper in sheet form, before its application to the cable, with a compound which is solid at the ordinary temperature, and at maximum working temperatures remains sufficiently viscous to stay in position, providing sufficient surplus of compound on one side of the paper to ensure ample flexibility in the wall of dielectric and also the filling of interstices between the edges of the convolutions of paper [illegible]

12. [illegible]

Assuming the use of the best materials, the necessary careful construction, and normal usage, it may be taken for granted that any appreciable deterioration of paper-

* [illegible]

[illegible]

[illegible] cables, and that sooner or later expansion and contraction [illegible]

An illustration of this is furnished by Fig. 10, which refers to expansion and contraction measurements on two 95 ft. lengths of 0·5 sq. in. concentric low-tension paper- [illegible] experiments under carefully controlled conditions.

Although only mentioned here to illustrate the point, it is necessary to state briefly the conditions of the experiments, which were as follows :—

The two lengths of cable, which differed only in the spacing and gauge of the wires comprising the outer conductors (entailing a slight difference in the total rigidity of the cables and a difference of a few mils in their overall diameters), were separately mounted on a series of rollers, one on each side of a central beam. It should be noted that this slight difference in longitudinal rigidity was insufficient to have the slightest effect on the flexibility, and was such as might be encountered any day between cables of different origin. In other words, the difference was so slight as to have no significance from any other point of view but the one under consideration.

In the twelve experimental runs referred to in Fig. 10 the rollers were fixed so that they could not revolve, the [illegible] throughout the lengths of cable. One end of each cable was fixed, and the other ends were sweated into brass blocks free to move in guides and geared to suitably graduated dials in order that the movement under heating conditions could be noted. At intermediate part[illegible] the one-third and two-third distances referred t[illegible] [illegible] roller used being freed for the purpose.

A continuous current of 750 amperes at suitable voltage was fed into the cables at the fixed end, cross c[illegible] being made to put the four conductors in series without interfering with the free movement of the cable at the other end.

The length of each run was determined by the time required to attain maximum expansion. For [illegible]

[illegible]

of the tests this time averaged $3\frac{1}{2}$ hours, and the temperature rise averaged 11[illegible]° F.

In Fig. 10, cable A is the more rigid and cable B the less rigid length. The values for the expansion and contraction are those recorded after cooling down (in the case of runs 3–9 after 6 days, and in runs 10–14 after 24 hours), the actual air temperatures being corrected to 65° F. Correction values were obtained from a separate series of

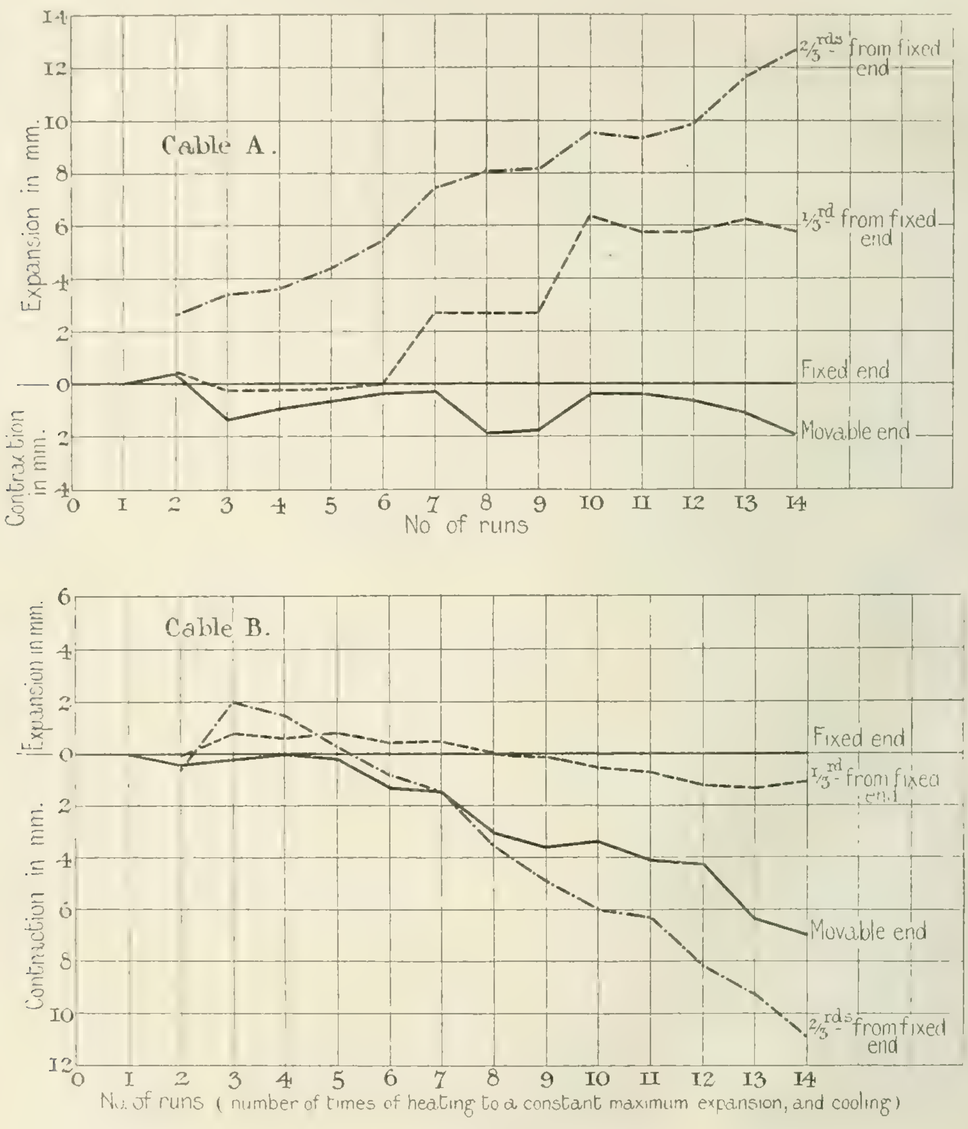


FIG. 10.

observations over a range of normal atmospheric temperatures.

It will be seen that the general behaviour of the two cables was entirely different, cable A tending to take up permanently and increasingly expanded positions, and cable B the reverse. An interesting feature in both cases is that the net result of the cycles of expansion and contraction entailed in this particular set of conditions produces the maximum effect at a part about two-thirds from the fixed end. The cumulative effect of the expansion in cable A, and of the contraction in cable B, is very marked in these parts. The ultimate results of such expansion and contraction, namely, the pulling out of conductors at joints, the fracture of lead sheaths, and other forms of damage, are too well known to engineers to call for further reference here.

The particular conditions illustrated above are chosen as roughly typical of those which obtain in a draw-in system, and many interesting comparisons and forecasts may be made from the results. The author regrets that pressure of other work has up to the present prevented this interesting study being carried to a conclusion, but the results summarized above are perhaps a sufficient demonstration of his view that little can be done to assist cables which are grossly overloaded, so far as manufacture and laying conditions are concerned.

[illegible] ductor and the actual or virtual external boundary of the [illegible]

[illegible] and draw-in systems.

The present Institution figures for current density, based on Messrs. Melsom and Booth's work, do not refer to [illegible]

The Institution Research Sub-Committee investigating the [illegible] searches will in due course throw much light on the subject. [illegible] as to the useful limits of the present Institution figures for current density, and the data on which they are based. [illegible] used at considerably higher current densities than those given in the Institution Wiring Rules do not attain such high temperatures as would be found by extrapolation of data obtained at lower current densities.

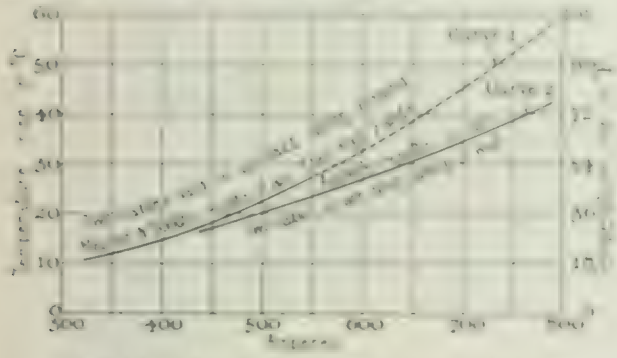


FIG. 11.—[illegible]

This is illustrated by the curves in Fig. 11. In the full part of Curve 1 are plotted values obtained on 0·5 sq. in. [illegible]

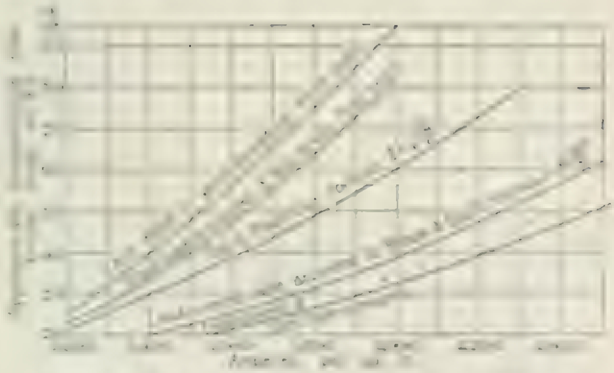


FIG. 12.—[illegible]

[illegible] obtained from actual tests at various current densities on a 0·1 sq. in. 3-core 30-kilovolt cable under two conditions of laying, with those calculated from the formula due to Apt and Mauritius—

$$I = [illegible]$$

where I is the current in amperes, t the temperature rise in degrees Centigrade, Q the sectional area of the conductor in square millimetres, and c a constant depending on the form in which the cable is made up, namely, twin, 3-core, etc., and also with Messrs. Melsom and Booth's formula—

$$i = K\left(\frac{D}{S}\right)^n$$

where i is the current density, D the [illegible] outside covering of the cable, S the secti[illegible] total copper, K a constant depending on the [illegible] rise under consideration and the system of u[illegible] and n a constant depending on the slope [illegible] connecting log i with log D/S.

It should be mentioned that the temperature rise in the case of the two upper curves was not contributed to by [illegible] research now in progress.

[illegible]

work has greatly improved. Probably the best results have been obtained where the general principle of making the joint as much like a specially reinforced part of the

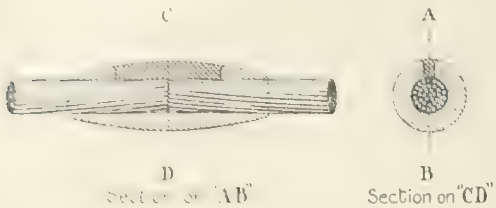


FIG. 13.

cable as possible has been consistently followed. One good reason for this is that there is clearly a much better chance of making a lead-sleeve joint watertight on a lead-covered cable than by using a cast-iron box which in many cases depends solely on the compound used for

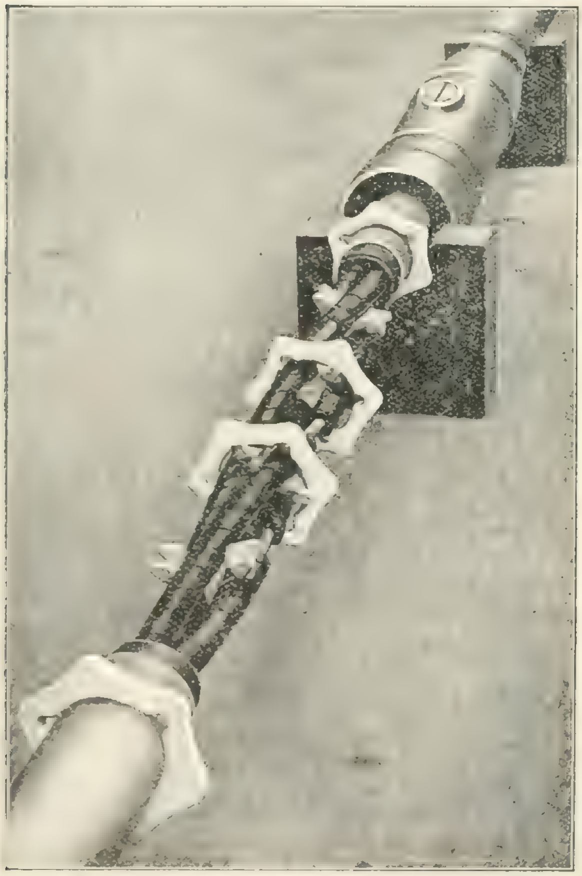


FIG. 14.

filling it to exclude moisture. The apparently simple process of filling a joint box really contains sufficient pitfalls to make it wonderful that joint troubles are not much more frequent.

At pressures of 50 to 100 kilovolts the necessity for avoiding any concentration of stress and weak paths (or combinations of the two) becomes very marked. So much so that construction which affords an ample margin of safety at working pressures up to 11 kilovolts becomes no longer permissible. The above-mentioned pressures of 50 to 100 kilovolts may be taken for this purpose as representing the margin of safety required at working pressures of 20 to 30 kilovolts.

First, the conductor-jointing ferrules must be designed in bold curves, and they must accurately fit the conductor before sweating. They should be fitted and finished off as shown in Fig. 13. The slightest excrescence of solder at the ends of the ferrule is a source of electrical weakness.

Wrappings of tape or paper for the purpose of insulating the copper joint are in the author's experience inadmissible, the chief reason being the risk of electrostatic discontinuity troubles or weak paths between the original insulation of the conductor and the applied wrappings. This risk may be minimized by suitable refinements of workmanship, but under even the best conditions of prac-

FIG. 15.

tical work there is a danger of a combination of electrostatic discontinuity and weak-path troubles. For this reason the author prefers to eliminate as far as possible the element of variable workmanship.

In Fig. 14 is shown a form of 3-core cable joint in which all wrappings or sleeves of fibrous insulating material are eliminated, the jointed cores being supported in specially designed porcelain "spacers," made of completely vitrified unglazed porcelain. These spacers,* illustrated in Fig. 15, are so designed that the two parts of which they are comprised may be put together after the joint is made, without straining the cores apart. They are specially shaped to resist any tendency to trap air or gases.

It is found that the effect of the presence of the porcelain spacer on the potential gradient, as regards any tendency to cause electrostatic distortion when the spacer is efficiently embedded in the compound, is negligible.

* Patent No. 21646/1913.

[illegible] lead sheathings has been fairly [illegible] of Trade [illegible] and earth [illegible] Continuity bonding and cross bonding [illegible] or checking such corrosion.

[illegible] systems have become [illegible] large systems. [illegible] course of time with the growth of a network is also appreciated.

[illegible] nections, in conjunction with lack of bonding, whereby local leakage circuits are set up, eventually giving rise to other leakage circuits. The extent to which this disease can develop under conditions of negligent maintenance has [illegible]

[illegible] sometimes blamed for the corrosion of lead coverings, a notable instance being that of the wooden bridges which used to be almost universally employed in the solid system of laying cables. The author has examined many cases of this kind which have occurred in this country and abroad, [illegible] action, the wood having formed the path for the current.

Apart from very exceptional cases—so exceptional as to be quite distinct from ordinary cable [illegible] be taken for granted that simple chemical action, as distinct from action assisted by current, is a cause of trouble which may be regarded as negligible with lead-covered cables.

[illegible] for mention, because the various sources from which it may arise are usually obvious. The author's attention was recently called, however, to a type of damage which is of considerable general interest, as it arises from conditions that are of modern growth, and are likely to be encountered in any large town where heavy motor lorry traffic exists.

A lantern slide shows three samples of 1·0 sq. in. single-core paper-insulated lead-covered cables selected from a number—kindly lent to the author by Mr. L. R. Lee, Mains Engineer to the Manchester Corporation Electricity Department—as illustrating various stages of development of the damage due to this cause.

The cables were laid solid in iron troughs at a depth of 4 ft. below the road surface, and had been in use for several years. Within the last two or three years a slowly spreading epidemic of faults of this character has arisen on lead-covered cables subjected to the concentrated pounding of the road surface resulting from the accentuated conditions of weight and speed of heavy traffic, and especially where service cables are taken across a street under the roadway. The effect of this pounding is slightly to depress the line of cable and troughing at the least rigid parts, *i.e.* the joints between lengths of troughing, [illegible]

Assuming that it is [illegible] troughing.

It should be remembered, however, that other methods [illegible] damage as the solid system, for the reason that when laid in pipes or ducts or directly in the soil the cable is comparatively free, so that the movement demanded is not concentrated on a length of a fraction of an inch, as it [illegible]

RUBBER-INSULATED CABLES

(1) PHYSICAL AND CHEMICAL PROPERTIES OF COMPONENT PARTS OF THE CABLE.

The physical properties of vulcanized rubber are fairly [illegible] time to time, but efforts to co-ordinate them with electrical properties have not been and cannot be successful, at least in the present state of the art. The reason of this is that maximum strength and elasticity are not compatible with maximum insulation resistance or dielectric strength. Especially is this true as regards the former, as may be judged from the fact that if we modify rubbers specially [illegible] taining maximum strength and elasticity, we may find that even so small an addition as 0·5 per cent of certain ingredients may result in a reduction of something like 50 per cent in the insulation resistance. This in itself might be comparatively harmless, but another extraordinary result from the electrical point of view is that in spite of the physical improvement the molecular structure [illegible] immersed in water for a few hours owing to the absorption of minute quantities of water, whereas insulating rubbers show no such alteration.

A further aspect of the matter is that in rubbers designed [illegible] critical stages of vulcanization, between which there are great differences in the dielectric strength. For instance, it is a comparatively easy matter to vulcanize a thick high-grade rubber dielectric—as used for e.h.t. cables—to a stage at which its insulation resistance would give no evidence, and mechanical tests very little indication, of under- or over-vulcanization by comparison with standards.

Yet its breakdown point may, under such conditions, be only one [illegible] of the value obtainable when vulcanization is carried a little further, or not quite so far.

In normal manufacture these critical stages are usually passed, but the fact that molecular structure and electrical properties obviously bear some sensitive relation to one another opens a wide field for investigation, and a series of curves connecting coefficients of vulcanization with dielectric strength and physical properties would be found intensely interesting, especially in conjunction with microphotographs showing the structure, if such photographs could be obtained.

An apparently anomalous feature of the case in which maximum strength and elasticity are aimed at, is that any improvement of the coefficient of vulcanization by vulcanizing "accelerators" tends to take the structure well clear of the critical points referred to, and so far may be said to improve the dielectric strength of the rubber, but at the same time it entails the relatively unsatisfactory condition as regards insulation resistance above described.

From the foregoing it will be noted that if it had happened that our standards had originally been based on dielectric strength and physical or mechanical properties, instead of primarily on insulation resistance, the co-ordination above referred to might have been more feasible.

(2) Conditions External to the Cable.

Working vicissitudes and other factors bearing on the durability of rubber-insulated cables may be divided into three classes, namely, those due to :—

(*a*) The natural deterioration common to all rubber goods.
(*b*) External influences due to working conditions.
(*c*) Internal influences chiefly due to manufacturing conditions.

With regard to (*a*), it may be taken as an axiom that, other conditions being equal, the rate of natural deterioration is slowest in rubbers made from hard fine Para rubber. Plantation rubber of the same botanical origin (*Hevea brasiliensis*) will undoubtedly in course of time reach the same level in this respect.

Under (*b*) come more or less simple chemical influences such as arise from direct contact with deleterious substances such as alkaline solutions, acid vapours, oxidizing agents, oils, solvents, etc. ; also indirect chemical attacks consequent on osmotic and electrolytic actions where incipient weaknesses in the dielectric allow such actions to arise. Under this category come effects due to leakage current along damp fibrous coverings. These happen largely near ends which are badly trimmed when connections are made. The access of moisture to the strands of a vulcanized rubber cable by way of exposed ends is a fruitful source of trouble. It should be appreciated that ordinary variations of humidity of the air may lead to this, even in situations which are apparently dry. Acid products are formed when the moisture comes into contact with the free sulphur which is always present to some extent in the rubber next to the strand, leading to corrosion of the conductor, and resulting in local action on the rubber by the copper salts formed. Powerful oxidizing effects occur on e.h.t. rubber cables where the production of ozone and oxides of nitrogen on the external surface of the dielectric is caused by brush discharges. Preventive measures against any of these external influences are obviously best applied in the form of special coverings made of materials having a maximum resistance to the particular deteriorating agent in any given set of circumstances. These coverings call for no special mention here, as they are sufficiently well known to most engineers.

With reference to (*c*), the internal influences due to manufacture chiefly relate to the deleterious effect of copper, by its catalytic oxygen-carrying properties, on rubber.

It has always been the practice to "tin" copper wires which come into contact with rubber ; but the fundamental importance of the perfection of the tin coating appears to have only become generally recognized within the last few years.

The tinning test devised by the author in 1897—in which cycles of exposure of the tin coating to hydrochloric acid and sodium-sulphide solutions consecutively are employed to indicate the comparative value of the tinning—has only recently been adopted by Government Departments at home and abroad, and by consulting engineers and large purchasers of cable in various parts of the world, although it has been in constant use in certain factories producing tinned wire ever since its introduction.

Unfortunately the original published description of the test* gave no details of the method of making up the reagents, because it was not anticipated that it would be so adopted.

For the efficient use of the test the sodium-sulphide solution should be prepared by dissolving 25 grammes of pure mono-sulphide of sodium in 100 cubic centimetres of water, adding an excess of sulphur and boiling for about one hour with occasional stirring. The solution should then be cooled, filtered, and diluted to the required specific gravity of 1·142. As there is a slight tendency for this solution to decompose on prolonged standing, depositing sulphur, it should be freshly prepared. The preparation of the hydrochloric acid is simply a matter of dilution to the required specific gravity.

In view of the misapprehension indicated by the wording of some cable specifications as to freedom of the tin from lead, and the brightness of the tinned conductor after vulcanization of the rubber, a few words on the subject of factors that matter may be of interest. With regard to metallic contamination of the tin, seeing that good commercial brands of tin do not contain more than 0·5 per cent of other metals (lead, bismuth, iron, antimony, arsenic, etc.), the tin originally used may be disregarded. Incidentally it may be mentioned that even 2 per cent of lead would not entail any technical disadvantage from the durability point of view.†

The influence of copper, which is the only metal that matters, may enter into manufacturing considerations in two ways, first by alloying with the tin in the tin bath and accumulating there to some extent, or secondly by imperfect application of the tin coating. A simple workshop method devised by the author to cope with the first possibility is based on the fact that the alloy may be

* *Electrician*, vol. 54, p. 843, 1905.

† The stipulation as to freedom from lead probably arose in the early days from the fact that lead is the chief impurity of tin, and from some appreciation of the desirability of keeping the tin as pure as possible.

[illegible]

In stranded conductors of high-grade rubber cables [illegible] The blackening due to sulphide of copper formed on exposed copper is readily distinguishable from discoloration due to tin sulphides. Neither the tin sulphides nor [illegible] to rubber. The blackening due to copper sulphide must, however, always be considered a detrimental feature if [illegible] action of the copper, and may therefore be considered as an intimate admixture of copper oxide and copper sulphide.

Microscopic examination and analysis of tin coatings [illegible] but this is probably due to the presence of copper alloy in the tin bath, and the application of the coating at such a temperature that the crystals may be picked up by the tin. The author has never seen any evidence of disappearance of tin by solid diffusion, although a very careful and prolonged research might conceivably show some such effect.

[illegible] with metallic (and, of course, oxidized) copper is the origin [illegible] by placing small quantities of copper oxide and the sulphides of tin and copper side by side on a sheet of pure rubber and warming for a few hours. The rubber under and around the copper oxide will be rendered soft and tacky, but will be unaffected where in contact with the [illegible] heat.

It will be gathered that as practically all the [illegible] noted under (*a*), (*b*), and (*c*) are superficial, heavy walls of [illegible]

* [illegible] between [illegible]

VULCANIZED BITUMEN CABLES.

(a) [illegible]

The general idea of the physical properties of vulcanized [illegible] ventilated.

[illegible] that [illegible] to tension, compression, and other mechanical strains have [illegible] rubber. The differences may fairly accurately be con- [illegible] "nerve" structure is broken down and it loses the above-mentioned properties to some extent. In this state its physical properties may be regarded as being "[illegible] with those of vulcanized bitumen at normal or medium temperatures.

(a) [illegible] *ture*.—To turn from [illegible] of vulcanized bitumen, the variation in consistency with a change of temperature has probably the most direct bearing on the subject from the cable user's point of view.

At very low temperatures (around or below the freezing-point of water) it tends to yield to sudden shock in a brittle fashion, breaking with a conchoidal fracture. At [illegible] and at still higher temperatures its cohesion disappears to a considerable extent, although its resilience appears to be increased.

As a result of this its manner of yielding to mechanical [illegible] by softening or by any process resembling the melting of bituminous, waxy, or resinous substances.

[illegible] this character the rate at which a given kind of stress is [illegible] compound which is moderately soft at medium temperatures will give comparative freedom from brittleness at low temperatures under normally applied bending stresses, but will show marked [illegible]

ture conditions when the bending stress is suddenly applied, i.e. approximating to the sudden shock above mentioned. This characteristic is referred to later, in connection with Fig. 20. At slightly elevated temperatures, initial softness is not an advantage, toughness being the most desirable property. On the other hand, hardness *qua* extrusion in the same way as the material is applied to cable conductors.

Fig. 16 shows how the most suitable diameter of rod is arrived at. It will be seen that under the shock or drop test, (*a*), the diameter of the test piece has a marked effect on the temperature at which failure occurs, but that—

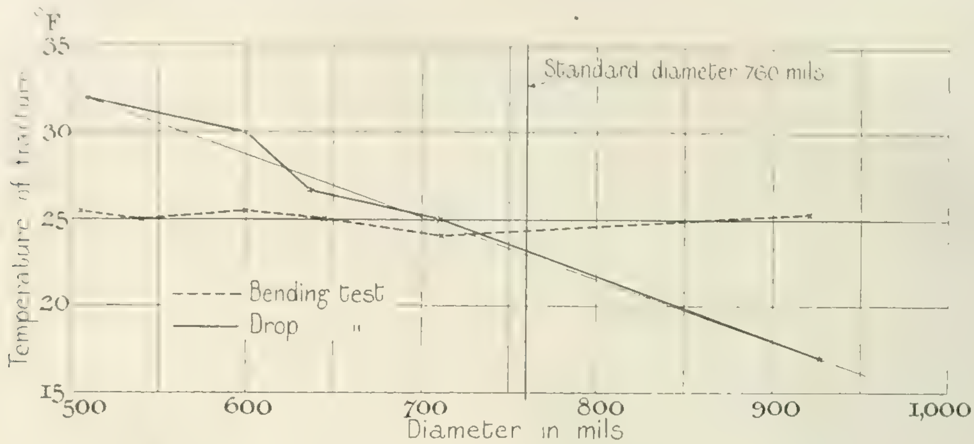


Fig. 16.—Relation between Diameter of Test-piece and Temperature of Fracture.

hardness has the general effect of raising the temperature range to a higher position in the thermometric scale, rendering it rather unsuitable for low temperatures. A material, intermediate as regards softness or hardness, possessing maximum toughness at medium temperatures, wide limits of temperature range, and approximately equal resistance to all kinds of stress at a low temperature, is obviously the most desirable.

(*b*) *Methods of testing, as illustrating physical properties.*—As an illustration of the foregoing remarks, a short description of routine physical tests devised by the author for the purpose of controlling the uniform maintenance of such a standard under manufacturing conditions, may be of interest.

These tests are as follows :—

(*a*) A shock test by which a standard blow is applied to the sample.
(*b*) A bending test applied at a standard rate of speed and at a standard radius.
(*c*) A penetration test constituting a control not only on the material but on tests (*a*) and (*b*) by ensuring that good results obtained from either of them are not due to slight softness.

With regard to the conditions of test, the lower end of the temperature range has been chosen for tests (*a*) and (*b*), taking advantage of two fundamental facts. First, for a given consistency of the material the range of physical properties is very constant for a given range of temperature, so that if the lower limit of the temperature range is fixed, the remainder follows. Secondly, that a given form of test sample withstands a definite mechanical stress at a certain critical low temperature, but fails under the same stress at a slightly lower temperature, even within 0·5 degree F.

The form of sample chosen as the result of a preliminary investigation is rod of circular section produced by

within limits—the temperature is approximately constant under the bending test. Naturally, the standard diameter of test piece adopted is that corresponding approximately to the intersection of the curves.

The extruded sample is divided into a number of short lengths. Samples for tests (*a*) and (*b*) are placed in a series of trays containing various proportions of glycerine

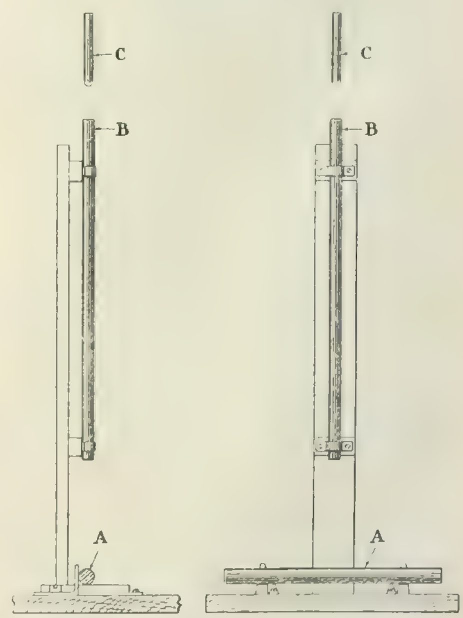


Fig. 17.

and water so as to control their final temperature after they have been cooled in a refrigerator, the results of the tests being recorded in terms of the temperature at which the samples survive.

Fig. 17 illustrates the simple apparatus used for

[illegible] the sample. [illegible]

[illegible]

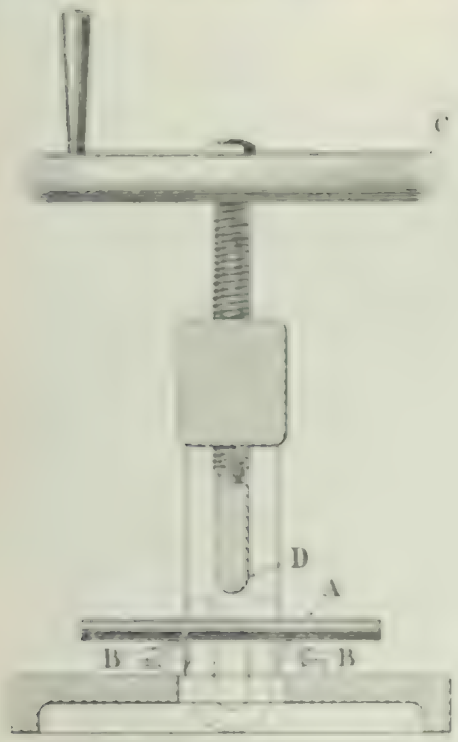


FIG. 18.

Fig. 18 shows the bending-test apparatus. The sample A is placed on roller supports B. The [illegible] flywheel, C, is rotated, causing the cross bar on which is mounted a tongue piece, D, [illegible] forcing the sample A into U form. The complete traverse occupies [illegible] seconds and breakage occurs in the early part of the traverse, if at all.

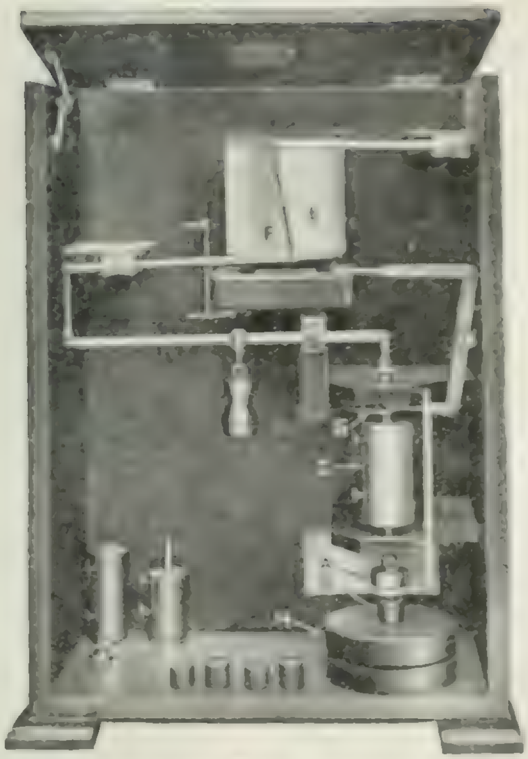
Fig. 19 shows the apparatus specially designed for the penetration test (*c*). The sample, B, after being maintained at 80° F. for half an hour is cut in a microtome and mounted in a recess in the table, H, and raised by rotating the table on a screw centre until the six [illegible]

By [illegible] the lever, G, [illegible] wards by the standard weight [illegible] the sample; and by the same movement the clockwork drum carrying the paper chart, F, is started, and the pen, E, traces a curve thereon which records the depth of penetration of the needles throughout a standard period of 5 minutes.

The curves produced in this way are compared with a standard curve.

Fig. 20 shows the standard curve (Curve 1) [illegible] the author, and serves also to illustrate the point [illegible] mentioned as to the possibility of softness being accompanied by brittleness (see Curve 2).

[illegible]



[illegible]

The average figure which the author pref[illegible] about 26° F.; the variation above and below this figure need not exceed 4° F. in ordinary manufacturing practice, and even these variations become averaged over large quantities of the material.

[illegible]

To pass from the physical properties of the material itself to the effect of the limitations thereof on cable [illegible] of component parts of cables in such manner as to supplement the physical limitations above-mentioned.

The two first-mentioned points are rather beyond the scope of this paper: the third is shown by the commercial success of well-known types of vulcanized-bitumen cable largely used under very arduous conditions, such as those which obtain in mining work. Twin and 3-core vulcanized-bitumen cables are more largely used under such arduous conditions than other types, and the fact that such cables are made without internal reinforcement by any other material, gives a good idea of the result of close attention to suitable assembly.*

(2) CONDITIONS EXTERNAL TO THE CABLE.

(a) *Chemical stability of vulcanized bitumen.*—With regard to chemical properties, the stability of vulcanized bitumen is remarkable. Unlike rubber, it is not appreciably subject to natural deterioration under normal conditions of atmosphere and temperature, and it may therefore be regarded as comparable with paper insulation in that causes of deterioration are practically always extraneous causes. So far as direct chemical attacks which may be encountered in practice are concerned, the material is exceptionally inert to the action of substances of an acid character. In fact, the author has for many years utilized vulcanized bitumen for the protection of other materials used in cable manufacture, such as lead, copper, rubber and steel from acid and oxidizing influences.

As might be expected from the fact that vulcanized fatty pitches, *i.e.* saponifiable substances, largely enter into the composition of vulcanized bitumen, it is much more susceptible to the action of alkaline substances. The direct action of such substances is usually, however, only superficial (to a greater or less extent, depending on the degree of free alkalinity), and it is a fact that even such severe conditions as continual exposure to coal-pit waters—which are usually of an alkaline character—have had no appreciable effect on vulcanized bitumen. Even if such waters contain free alkali equivalent to 25–30 grains per gallon (estimated as sodium carbonate), which is considerably above the average for waters encountered in coal-mines in this country, and the vulcanized bitumen is freely exposed to their attack for 2 or 3 years, the depth of penetration of the action is inappreciable. Waters of a brackish character which sometimes occur in coal-mines near the sea and elsewhere, and which may contain 1,000–1,300 grains per gallon of the chlorides of sodium and magnesium, have no action on vulcanized bitumen.

Although not coming strictly under the category of chemical deterioration, it may be permissible for the author to digress for a moment to correct the fallacious impression which exists in some quarters, and which has recently been perpetuated in a Board of Trade Report,† that vulcanized bitumen is softened by contact with coal gas.

The statement is correct for natural bitumens, pitches, etc., but is decidedly incorrect for vulcanized bitumen.

(b) *Secondary chemical attack on negative cables; softening by saponification.*—Leaving the causes of deterioration due to direct attack, and turning to secondary causes, it is obvious, and moreover well known, that the susceptibility of alkaline attack must have a great influence under continuous-current fault conditions which can produce electrolytic action, because in most soil conditions it is possible not only to form alkaline substances at parts which constitute the virtual negative electrode of the leakage circuit, but to force such substances by osmotic pressure through the dielectric to the negative conductor. Under these circumstances both the direct action on the vulcanized bitumen of concentrated alkaline substances and the aggravated conditions due to the passage of current (producing continuous supplies of deleterious matter and forcing them to the best position for attack) come into play.

This form of secondary deterioration has been dealt with by Messrs. Dick and Fernie in their book on "Electric Mains and Distributing Systems." These authors devote considerable argument to proving, on the evidence which they describe, that thinning, softening, and destruction generally of the vulcanized-bitumen wall is due to the direct action of alkaline substances resultant on leakage current, possibly assisted by osmotic effects. They do not presuppose faults in the insulation to account for the leakage current, but on the assumption that "nearly all insulators conduct electrolytically at high temperatures" suggest (page 172) that current may pass through the insulation by electrolytic conduction when the cable is hot and has its insulation resistance consequently lowered. Even if this assumption be accepted, it is obviously a matter of degree, and the following brief summary of experiments having a bearing on this point, though originally designed for another purpose, may be of interest at this juncture.

(c) *Source of current producing saponification effects on negative cables.*—The experiments were made on thin sheets of vulcanized bitumen placed between electrodes and subjected to a potential difference of 250 volts (continuous current) under various conditions. Frequent readings of the current were taken on an instrument reading to 0·2 micro-ampere.

(1) Calendered sheet of vulcanized bitumen, thickness 18 mils, between two flat circular tinned brass electrodes 3 in. in diameter. Heated to 180° F. in an electrically heated oven for 3 weeks. No measurable current passed.

(2) Repetition of (1), but the sample was previously immersed in water under pressure. No measurable current passed.

(3) Repetition of (1) and (2). In case abnormal solidity had resulted from calendering the vulcanized bitumen to a small thickness, the samples in this case were cut from vulcanized bitumen extruded from a forcing machine in the ordinary way, by means of a coarse microtome. The thickness was 22 mils. Lead weights were used to improve the contact of the electrodes, as the surface was not so good as in the calendered samples. No measurable current passed during a fortnight's heating.

(4) Repetition of (3). In this case, in order to get over the contact difficulty, the samples were clamped between two glass cells with mercury forming the electrodes. No measurable current passed in the case of the dry sample in one month. In the case

* The mechanical efficiency of such construction was demonstrated in an article contributed by the author to the *Electrician*, vol. 71, p. 617, 1913.

† Report of Board of Trade Committee on Electric Mains Explosions, p. 4. 1914.

of the wet sample the new form of application of the electrodes resulted in a reading of 20 micro-amperes due to surface leakage. This diminished to zero in 24 hours, and no current passed thereafter.

(c) As the moisture forced into the sample would naturally tend to be dispersed in course of time under the conditions of temperature maintained during the foregoing experiments, an attempt was made first to absorb a larger amount of water by subjecting the sample to a vacuum of [illegible] and then admitting water to it under pressure, and, secondly, to allow the absorbed water to be retained by conducting the experiment at the temperature of the room. Otherwise conditions were as in (b). No measurable current passed during a month's run.

From the results of these experiments it would appear that a dielectric must first be rendered conducting, for example, by possible influences, incipient flaws, damages, or general weakness, before it will allow sufficient current to pass through it to form electrolytic products in its vicinity. In other words, the dielectric does not, under the influence of temperature solely, permit the sequence of events described by the authors above quoted unless incipient fault conditions are first set up.

To return to Messrs. Dick and Fernie's statements on the subject generally, they record various observed facts and experimental results in connection with the ordinarily accepted sequence of leakage, osmosis, formation of alkaline substances, softening effects on negative cables, and immunity of positive cables, and so on. These statements are generally true, but they only form part of the whole truth.

(a) *Physically similar but chemically different effects on alternating-current and positive and neutral continuous-current cables.*—We have only to accept the facts that physically similar effects have been known to occur on alternating-current cables, both 3-core and single; that positive and neutral cables on 3-wire continuous-current systems have exhibited the softening symptoms indiscriminately; that cables above ground have been similarly affected; and that the effects have been sharply localized, with a well-defined line of demarcation between softened and normal parts having the same facilities for conduction through the dielectric, to realize that there is yet much to learn about the subject.

As a matter of fact, the author arrived at the conclusion several years ago that there existed a distinct type of deterioration different from the saponification effect described by Messrs. Dick and Fernie as softening. The search for evidence on the point was a slow matter, because it was necessary that it should be of a practical nature and furnished as a product of working conditions. That is to say it had to consist of samples of faults in which the saponification effects were absent, and yet showing similar physical characteristics. The evidence had to be born, not made, to be reliable and of value. It came first in a very curious form.

A fault had occurred on a length of 37/13's high-tension 3-core solid bitumen armoured cable working at 2,000 volts 3-phase installed in a pit shaft. The shaft was full of steam, and the temperature varied between 75° and [illegible] F.

No burn-out had occurred, but on test [illegible] a leakage to earth of about 20 amperes had been noted. The resistance of the fault was too high for it to be located by a loop test, and in attempting to [illegible] working conditions [illegible] a heated area a few feet in length was discovered. [illegible] When [illegible] the commencement of the fault [illegible] and there was no trace of mechanical damage [illegible] it was fixed [illegible] up between the

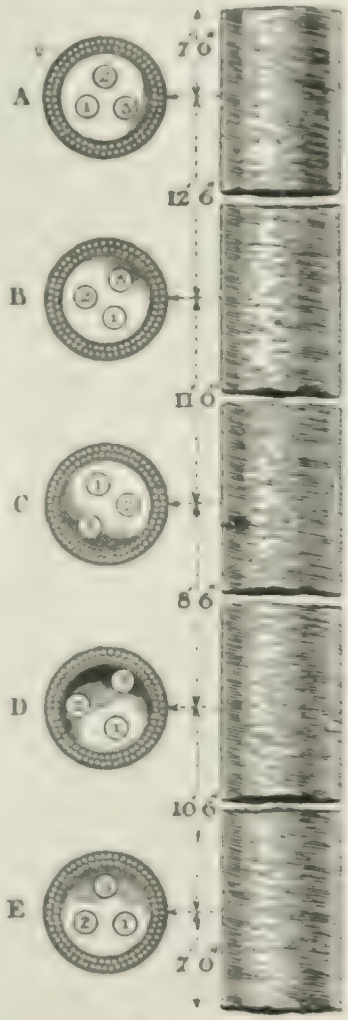


Fig. 21.

faulty core and the armour. Dissection of the interior part of the cable revealed an extraordinary condition of affairs, in that each of the conductors was found to have been displaced in an outward direction, one of them to a greater extent than the other two.

This is illustrated in Fig. 21, in which the sections A, B, C, D, and E represent the conditions at the intervals indicated, No. 3 being the faulty core, and D the part at which the fault had originated.

At D the thickness of vulcanized bitumen between the conductors and tapes (originally 220 mils) was reduced to about 100 mils on conductor 1, 50 mils on conductor 2, and 15 mils on conductor 3. At and below E the tendency for the cores to return to their normal positions was quite marked. On the upper side of D at points B and A, the normal positions and original thicknesses of the insulation between the cores and between the cores and the tapes had been approximately reverted to.

The normal tendency of the conductors in a 3-core cable is of course to crush together, and some extraordinary conditions must have arisen in the shaft to bring about this peculiar distortion. This conclusion was confirmed shortly after by the total collapse of the shaft, which was a very old one.

In Fig. 21, the cross hatching in the sections A, B, C, D, and E, is intended to represent softened parts of the cable, the extra heavy hatching indicating a degree of softening which allowed the compound to flow gradually when the outer coverings were stripped, the lighter hatching representing soft to slightly soft compound, and the unshaded parts the unaffected vulcanized bitumen. It will be seen that the softening followed the faulty (No. 3) conductor closely, and also that it tailed off as the normal position of the conductors was reverted to. The coincidence of the softening with the faulty core is important.

The factors which evidently produced the deterioration in this case were heat, current, and possibly moisture, in conjunction of course with an unknown time element. Prolonged heating by ordinary means would not by itself permanently soften the vulcanized bitumen to the consistency found in the softer parts. Although the heat had been produced by the current in this case, it was fairly evident from the coincidence above referred to that the current had some effect other than $I^2 R$ heating.*

Chemical examination showed that there was an absence of the usual formation of free alkali in the fibrous wrappings of the cable, and the softened bitumen showed no trace of saponification. This was not surprising, because from the method of installation the moisture contained in the tapes and jute bedding was not likely to contain such substances in solution as would usually be found in the vicinity of a cable laid in the ground or drawn into ducts. These instances, therefore, afford a confirmation that softening effects on bitumen cables could be produced which were apparently physically similar but chemically different, and brought about by means different from the commonly known saponification effects. It may be added that analysis did not reveal that anything of the character of de-vulcanization had occurred.

Great difficulties in the way of regulating the conditions were found in attempting to reproduce experimentally the softening effects found in the sample length; in fact at that date every effort to do so failed. The deductions, previously mentioned, drawn from the evidence as to the causes contributing to the production of this type of softening, therefore lacked proof at this date.

(*e*) *Investigations in the tropics*—Considerable addition to the knowledge of facts was made as the result of some investigations which the author had the opportunity of making some time later during a trip to the East, and a résumé of some of the evidence obtained may be of interest at this stage.

The cases described are typical of a large number of each kind, and all facts in connection with the investigations were recorded in detail, in conjunction with others interested in the investigations, before attempting to arrive at conclusions as to causes.

The first interesting feature was that the softening was in no case found to affect a whole length of cable. In some cases only a matter of inches in length of deteriorated bitumen separated parts which were normal; in other cases yard after yard was found to be affected, often more on one side of a cable than on the other.

This clearly showed that variations in material could have no relation to the trouble, because from the nature of the manufacturing processes the insulating material must always be averaged over at least some hundredweights, whereas the deterioration frequently affected only ounces of it.

Another interesting feature was that the local softening occurred indiscriminately on positive, negative, and neutral cables. Again, there was nothing common to the deterioration in the degree of exposure of the cables due to methods of laying or installing. The cases examined comprised direct-laid armoured cables and unarmoured cables laid solid in iron troughing, as well as cables in feeder pillars which were more or less out of continuous contact with the ground or with earthed structures.

In some cases badly deteriorated cables were found adjacent to normal ones in the same trough or feeder pillar, apparently subjected to the same conditions and influences, showing that climatic influences *per se* could not be responsible for the trouble.

Cables in stores furnished no evidence whatever of deterioration, showing that tropical temperature alone did not affect the insulation.

Many other points were investigated in minute detail, and the general mass of positive and negative evidence was broadly tested to find some common ground for the observed facts. Soils, waters, temperatures, insects, equipotential points and zones on networks, geographical relationships to generating or distributing centres, and other conceivable factors were examined with the object of deducing some positive or negative conclusions. For some time no conclusion could fairly be drawn from the evidence afforded by dissection of the cables and observations in regard to their surroundings, when tested against the various potential factors which might have some physical or chemical influence on the insulating material.

Then came an opportunity of examining several long services of paper-insulated vulcanized-bitumen sheathed wire-armoured cable on which faults had occurred, and which were being replaced. The average service in the East is much longer than at home, and it occurred to the author that a complete service would form for investigation purposes a sort of miniature parallel to the distributor and feeder systems, and would be more likely to produce concise evidence than isolated samples taken at various parts of a network, since they could be examined from end to end. In every faulty service

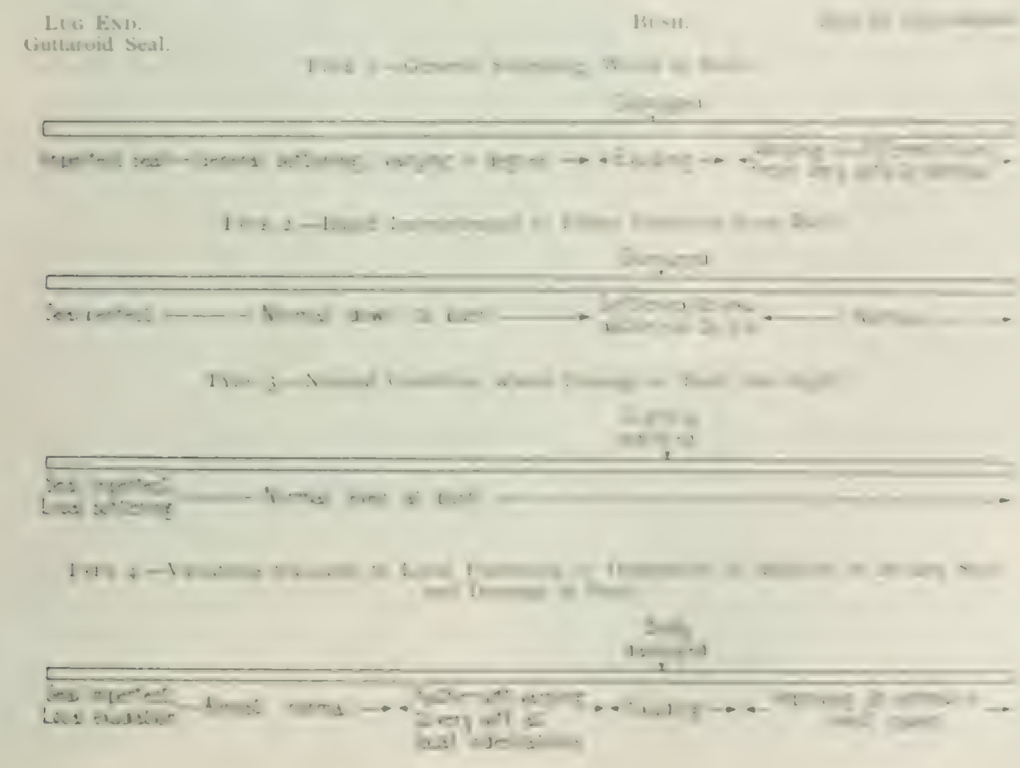
* Since the date of this investigation (1911) two instances of similar softening effects at or near faults have come to the author's notice on unarmoured single-core cables fixed in grooved wooden casing, and used on high-tension 3-phase circuits. In these cases $I^2 R$ heating could not have been an appreciable factor on account of the high resistance of the faults.

[illegible]

Having [illegible] the leakage current and the softening effect, it remained to test the knowledge thus gained in other cases which were not so concise and well defined.

[illegible] ...ned, but where the [illegible] extent of the [illegible]

It [illegible] variations which can enter into effects that have been several years in the making, tend to make direct deductions as to the [illegible] following [illegible] several [illegible] other section and feeder pillars were [illegible] check points arising during the investigation.



In surveying the grouping shown above, it will be appreciated that where damage occurs at the bushes and at the lug-end seals on adjacent cables of different polarity, subsidiary leakage circuits shunted off the main leakage circuits between damaged positions at the bush may be set up along the cable coverings if the latter are of sufficiently low resistance to allow appreciable current to pass between the damage at the bush on one cable and the damage at the lug seal or elsewhere on a neighbouring cable. This would be the case under wet-season tropical conditions, and it will be seen that types 1 and 4 are favourable to this leakage circuit formation and that types 2 and 3 are not, and that the degree and distribution of softening are in accordance with these facilities. That such shunt leakage circuits had actually existed was proved by the distribution of certain staining effects on the tape coverings of the cables, produced by an osmotic process due to the passage of current along them under conditions of considerable humidity. Proof of this is too lengthy to be described here, but it may be stated briefly that the facilities for the passage of current and also the evidence of it having passed generally coincided with the degree and distribution of the softening effects.

It will be appreciated that the whole of the tropical instances here referred to were particularly bad ones, and occurred under conditions of installation which should never have existed.

The difference between the maintenance requirements and conditions of systems of solid-laid metallic-sheathed cables and of non-metallic sheathed cables respectively, and the relative likelihood and uncertainty of faults rapidly declaring themselves, is well known to engineers. In the latter case, this feature combined with faulty installation would naturally tend to produce exaggerated cases of deterioration. It will also be understood that it is not easy, and certainly not justifiable, to draw conclusions from the examination of one or two isolated cases, but the evidence obtained from a large number of cases with due consideration of local conditions and surroundings, puts the deductions drawn therefrom on a very different plane.

(*f*) *Summary of results from investigation in the tropics.*—The result of the investigation of these instances in the tropics may be summarized as follows :—

First, they showed that leakage current played a prominent part in bringing about softening of the vulcanized bitumen, and that such currents even of a very minute order would produce a type of softening other than that caused by saponification in the well-known manner.

Secondly, that moisture must have been a factor in the case, although it was not proved that it had any other function than that of rendering fibrous coverings and other paths conductive. The relation of the distribution of stains in tape coverings to that of softening of the vulcanized bitumen is confirmatory evidence of its presence.

Thirdly, it appeared likely that, in the presence of the two preceding factors, this particular form of softening occurred more readily in tropical than in temperate climates, and that temperature was therefore also a factor. (Climate would of course affect both the second and third factors, the alternations of temperature and moisture being extreme in most tropical countries.)

Fourthly, time is obviously important in all changes of the kind under consideration.

The results therefore confirmed the tentative conclusions drawn from the instance to which Fig. 21 refers. The relationships between the four factors were unknown,

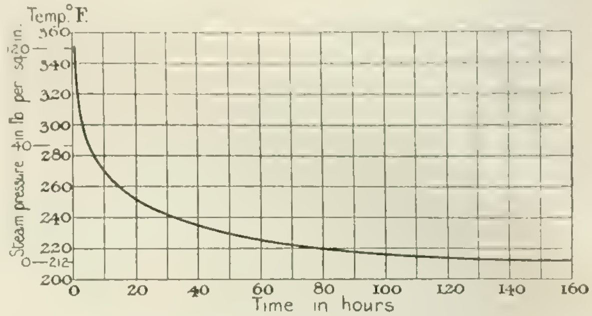


FIG. 22.—Approximate Time required to produce Softening in Steam at Various Temperatures.

although the individual effects of them or even of a normal combination of them was known to be negative for such periods as represent the lifetime of sound cable, but remained to be investigated in an abnormal combination.

(*g*) *Experimental reproduction of the second type of softening.*—Attempts to reproduce the softening experimentally under

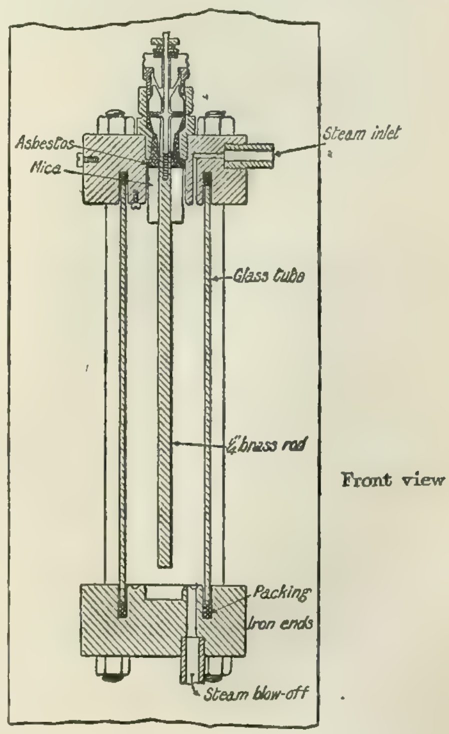


FIG. 23.—Steam Pressure Apparatus.

approximately similar conditions to those noted in the *in-situ* investigations had to be abandoned after a few months as no positive results were obtainable even when some of

the conditions were somewhat exaggerated. Other series of experiments were designed with the object of producing the softening under very exaggerated conditions, and then introducing or varying one factor at a time to determine its relative bearing on the matter.

The results of a number of preliminary experiments showed that some softening could be produced by the combined action of heat and moisture. Also that the time element, which even under faulty electrical conditions might be years, could be reduced to weeks or even hours by varying the temperature. The general relation between the time required to produce pronounced softening and the temperature in an atmosphere of steam under pressure is indicated in Fig. 22.

In order to include the factor of current in this accelerated process of producing the softening effects, the apparatus shown in Fig. 23 was designed and made for treating samples in steam at temperatures from 212° F. to

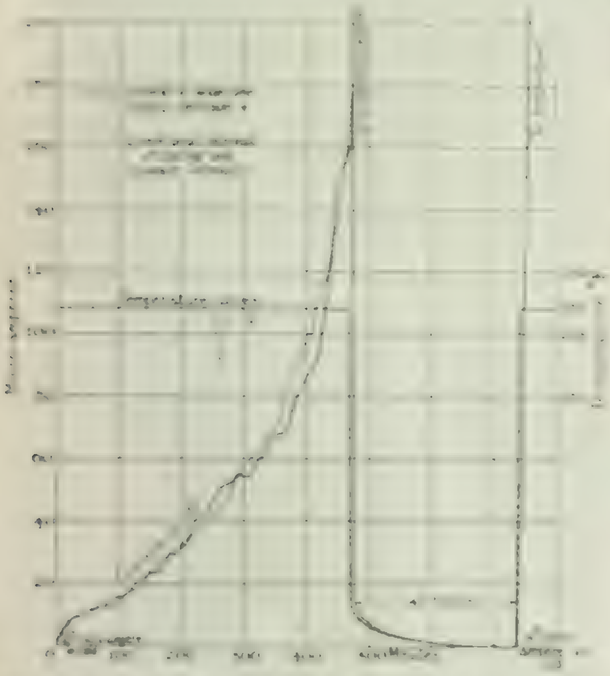
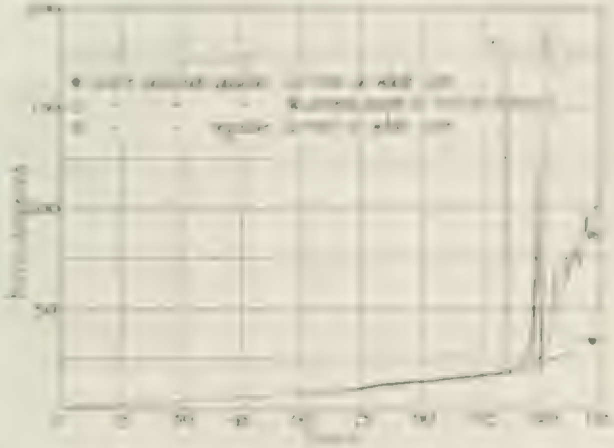


FIG. 24.—Current Curves of Two Samples of Vulcanised Bitumen in Steam at 287° F. (40 lb. per sq. in. pressure).

about 290° F., the samples under test (0·25 in. radial thickness) being mounted on the central brass rod acting as one electrode, and covered with a fine braid of copper wires earthed to the apparatus as the other electrode. The rate of transition from the normal to the softened state could be closely followed by taking readings of the current passing between the electrodes, a potential difference of 250 volts (continuous current) being used either continuously as a working condition, or switched on at intervals for test purposes.

A disadvantage of working under these accelerated temperature conditions is that the relationship of the factors which enter into the case in practice are disturbed. For instance, in practice the effect of current must be relatively slow, and it was not surprising therefore to find that it vanished when the other factors were exaggerated so that the time is reduced from years to hours. This is illustrated in Fig. 24, which shows that two samples subjected to steam at 40 lb. pressure, 287° F., broke down [illegible] after identical periods of time although current was flowing continuously in one, and only at intermittent intervals for test purposes in the other.



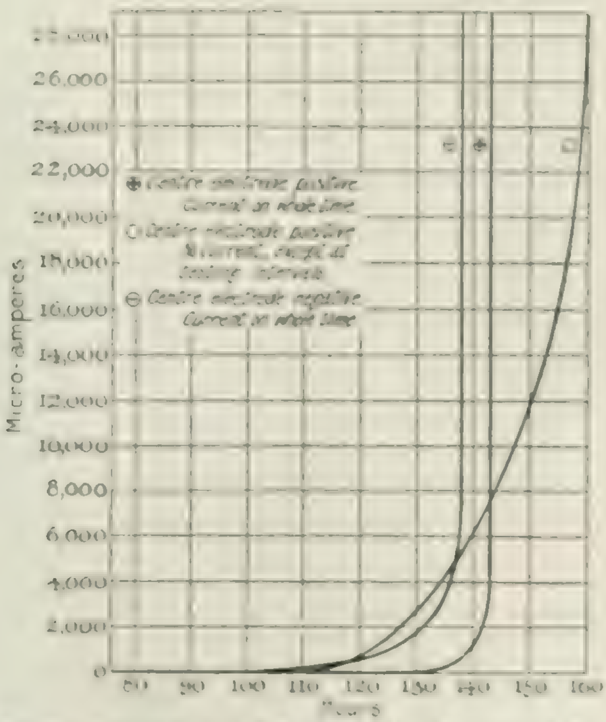


FIG. 25.—Current Curves of Three Samples of Vulcanised Bitumen in Steam at 212° F.

Fig. 25 shows that when the temperature is reduced to 212° F., and the time to attain softening (as indicated by electrical failure) is thereby extended to about 150 hours, the effect of current applied continuously throughout the heating period [illegible] apparent. The three samples referred to in the diagram were simultaneously treated, in order that the results obtained from [illegible]

be strictly comparable. The almost simultaneous failure of the positive and negative (centre electrode) samples, accompanied by the arrival at a certain fairly-well-defined degree of softness, bears some relation to the author's observations as to softening of this character being independent of polarity.

Physical nature of the process producing the second type of softening.—In the earlier stages of the investigation, as already mentioned, it was proved that the physical changes were not due to anything of the nature of spontaneous or chemically induced de-vulcanization. In the light of experimental reproduction of the softening effects described above by the combined agency of heat and moisture (steam), hydrolysis of the glycerides of the fatty and hydroxy acids contained in the vulcanized bitumen was clearly indicated. The results of analysis of the softened material, and a comparison thereof with the results obtained with the original vulcanized bitumen, confirmed this indication.

The normal free acid in the raw materials is not increased by vulcanization, although it probably exists thereafter as sulphurized fatty acid. The process of softening, however, was found to be accompanied by an increase in the amount of free acid, roughly in proportion to the degree of softening, the amount of acid being approximately doubled in the case of moderately softened material, and trebled in cases of considerable softening.

The general nature of the decomposition by hydrolysis is similar to that by saponification, except that in the former the fatty acids are not combined with an alkali and therefore do not form soaps. This throws some light on the indiscriminate occurrence of the former type of softening on cables of any polarity and on alternating-current cables, and the restriction of the latter type to negative continuous-current cables.

The increase in the amount of free acid which accompanies softening has, as might be expected, a marked effect on the solubility. For instance, the organic matter of the softened compound is almost entirely soluble in benzene, whereas only about 50 per cent of the organic matter in the normal vulcanized bitumen is soluble.

Means of obviating the second type of softening.—The ultimate object of the study of the softening effects was naturally to find and provide some means of obviating them; and in view of all the facts brought to light by investigations *in situ* and experimental work, the best direction in which to work was obviously one in which protection would be afforded to the susceptible components of the material. One had to accept the economic situation that the material had a distinct field of its own in electrical engineering practice, and disturbance of this situation by appreciably adding to the cost, or invariably providing waterproof coverings (such as lead) in order to exclude moisture, was distinctly undesirable.

Some form of colloidal filling having the requisite physical properties to allow of its incorporation with the vulcanized bitumen, of such composition as not to be capable of decomposition by hydrolytic action, and which at the same time would exert a maximum protective effect when present in small proportion, was clearly the ideal. After much experimental work it was found that high-grade vulcanized rubber could be treated in such a manner that it would fulfil the requirements as regards incorporation with vulcanized bitumen, and would in addition exert a surprising degree of protection against hydrolytic and selective action, even when used in small proportions. In fact, there was apparently some kind of mutual protective action, because the resistance to softening under the steam-pressure conditions previously described was greater in the combined substance than in either of its components.

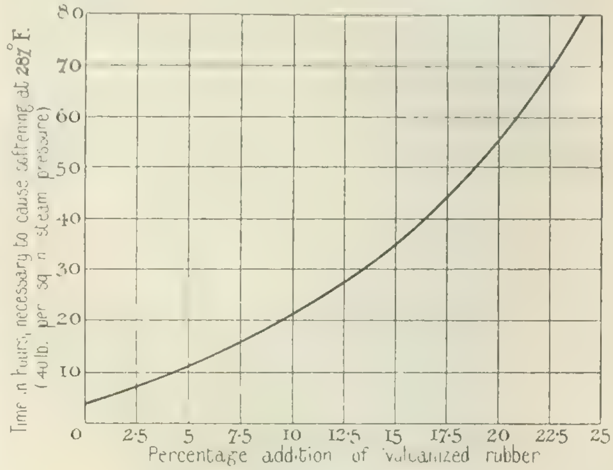


FIG. 26.

Fig. 26 records graphically the results of a series of tests on the degree of protection afforded by various percentages of vulcanized rubber when subjected to steam at a pressure of 40 lb. per sq. in., the softening periods being determined by observation. It will be seen that the addition of about 6 per cent of vulcanized rubber trebles the time required to produce the softening, and that up to about 12 per cent the time is proportionately increased. When larger proportions are used the curve rapidly becomes steep, and at 40 to 50 per cent the protection from softening effects appears to be infinite. Remembering that the softening action only occurs under faulty conditions and requires five or six years to develop to a troublesome stage, the protection afforded by 5 to 10 per cent of the rubber substance would appear to be ample under the worst conditions of practice.

The author feels that some apology is due for the length to which this latter section of the paper has grown, but he feels sure that there are a large number of engineers who will be glad to have a more intimate knowledge of the properties of vulcanized bitumen cables, and who will derive some satisfaction from the assurance that the troubles referred to are not inherent in the type of cable, but are attendant on fault conditions which should seldom occur, and which would equally produce some kind of trouble on any other type of cable.

The author's thanks are due to his assistants, Messrs. Fairfield, Crellin, and Gale, for their help in many of the investigations referred to in the paper.

DISCUSSION BEFORE THE INSTITUTION [illegible]

[illegible] sheath method, and on consideration I was convinced that [illegible] other. The drawback to the Jona method is the assumption that the inductivity—that is, the specific inductive [illegible] nating pressures the capacity currents in the inter-sheaths [illegible] it is necessary first of all to calculate the potentials at which the various inter-sheaths have to be maintained in order that the pressure may be equalized across the dielectric. In Fig. 6, for instance, there is one inter-sheath. If the difference of potential between the inner conductor and the lead sheath were, say, 50,000 volts, then the difference of potential between the inner conductor and the inter-sheath would be about 20,000 volts, and the difference of potential between the inter-sheath and the lead sheath would be about 30,000 volts. Hence, by maintaining these differences of potential constant the electric stress is equalized and the factor of safety of the cables is thus increased. It is obvious that the capacity between the inter-sheath and the lead sheath is much larger than the capacity of the original cable, so that at first sight the capacity current on the inter-sheath might be expected to be large. Fortunately, however, the capacity current on the inside of the inter-sheath is flowing in the opposite direction to the capacity current on the outside, and thus the actual capacity current on the inter-sheath is the difference between these two currents. The actual inter-sheath current, therefore, is not large. The capacity current on the inner core, for instance, may be 1 ampere per mile, and on the inter-sheath it may be, let us suppose, 1 ampere per mile also. On the lead sheath outside it must be 2 amperes per mile, as it must equal the sum of the two currents. No matter how many sheaths are used, if their potentials be properly maintained, the capacity current in the lead sheath outside is equal to the sum of all the currents in the inter-sheaths plus the current on the [illegible] for longer lengths, but [illegible] that way. I think, [illegible] in the habit of referring to this inter-sheath met[illegible] In this case the va[illegible] tained at the proper potentials by leakage currents, [illegible] very much smaller than the corresponding capacity currents, so that the arrangement is quite suitable for very long lengths of continuous-current cables, such as are used [illegible] the latter case the capacity currents in the inter-sheaths are all equal.

[illegible] comprehensive paper on the subject of cables from the [illegible]rer's point of view is more than due. Th[illegible] who both dealt with the subject theoretically rather than from the point of view of difficulties encountered in manufacture. On page 59 the author advocates the use of a lead tube as a core in order to reduce the high electric stress set up by a conductor of small diameter. This [illegible] laid. It would be very interesting to hear how t[illegible] potential has been fixed, whether by the use of [illegible] present. The author mentions on page 64 some [illegible] ments which I made on the superposition of a continuous on an alternating potential. During the last few months [illegible]

Mr. Rayner. manufacturing firms with, I understand, useful results in certain directions. I am hoping that these results will be published before long. The author suggests that the results given in my paper were due to a change in the capacity of the dielectric. I think the experiments show quite definitely that this is not the case, and that the effect is largely due to the great decrease in resistance of the insulating material at high temperatures. I suspect that curve No. 1 in Fig. 9 on page 64 is also due in large part to a similar cause, and cannot all be ascribed to a great change in the dielectric constant. I now come to the part of the paper which might have been the most instructive, namely, a description of the components of the insulating materials used in paper cables, and of their physical properties. The author seems to have omitted the foundation stones on which I hoped he would build a reasoned account of the development of modern insulating materials. Omitting the paper which is little more than a distance piece to keep the conductor in the centre of its tube, the author gives no definite information as to what is the composition of the insulating material. It is, I believe, generally a mixture. What are the properties of the components of the mixture, and what regulates the proportion of the ingredients? How do the important qualities required of a highly stressed dielectric change with a variation in the composition of the materials used? What is the value of the dielectric constant and of the power factor, and how do these vary when the temperature changes? How do rubber and bitumen cables compare with paper cables in these respects? These are fundamental points, and a paper dealing with cables which omits all reference to them cannot be considered altogether satisfactory. For instance, take the question of power factor. Höchstädter gives this as 2 to 3 per cent. The value is, I believe, often appreciably less than this. Without information on such fundamental physical characteristics it is impossible to estimate how they limit engineering possibilities. I hope, therefore, the author will be able to supply some information on these points and thereby considerably increase the value of the paper.

Mr. Hunter. Mr. P. V. Hunter: In the circumstances mentioned by Dr. Russell, from a knowledge of the conservatism of cable makers in general, we might have expected a paper of a decidedly tentative nature. In so far as it deals with future developments, however, this is far from being the case. After introducing his subject by referring to what has been done by others, the author deals with the present standards adopted by cable makers and condemns them absolutely. He then assumes, by inference rather than by actual language, that any substantial advance in the use of 3-core cables for higher pressures is impossible, and he points out the advantages of single-core cables. This is certainly a step beyond present-day practice, but not content with this the author refers to the inter-sheath cable as being superior to the ordinary single-core cable. I feel that for anyone actively engaged in the manufacture of cables to read a paper dealing progressively with the subject in this way is a great advantage to the Institution. Turning to the first point considered by the author, namely, the present cable standards, it seems to me that something should be done to revise them. I thought at one time that this might be effected by simply promoting them a step, that is to say, using 2,000-volt cables for pressures in the neighbourhood of 5,000 volts, 5,000-volt cables for 10,000 volts, and 10,000-volt cables for 20,000 volts; but even then the present standards are rather unsatisfactory, because, as the author points out, the thickness of the dielectric is greater as the size of the core increases, which appears wrong according to theoretical considerations. The paper may be taken, so far as it relates to progress in high-tension work, as recommending single-core cable. I agree with the author that single-core cables will have a larger field in the future, and it is for us to anticipate as quickly as possible exactly what that field will be. At present there are quite a number of instances of very high-pressure single-core cables being used, but generally for one particular purpose only, namely for connecting in series with overhead lines, where the lines have for some reason or other to be taken underground. We should not expect to see single-core cables limited to that particular application. I feel certain, however, that conditions will arise which will limit the use of such cables to applications of a similar kind; that is to say, I think it will be impossible to supersede the present 3-core cable by single-core cables for general use in large and complicated transmission systems. I feel, too, that before single-core cables are adopted on a really extensive scale it will be necessary to consider one or two aspects of their use which may lead to engineering difficulties. First of all, the capacity current will be extremely high, and also, owing to the fact that the conductors are placed some distance apart, there will be increased reactance, which in the case of long lengths may lead to a revival of the Ferranti effect as a matter of practical importance. This effect may be said to be that condition in which the reactance voltage adds effectively to the working voltage of the circuit; that is to say, it is a condition which may be produced only by a current that is substantially leading. It is experienced in a small and modified form in cable testing. In testing a 20,000-volt cable at 40,000 or 50,000 volts the effective ratio of the testing transformer will increase quite appreciably, and I fear that it will be necessary with single-core cables to take steps to deal with a similar effect, although in this case the reactance is provided by the cables themselves One method is to alter the power factor of the current taken by the cable at no load. The next trouble which should be anticipated is that where three single-core cables are used for 3-phase working, in the event of the lead sheath of two of the cables touching at two points, a heavy circulating current will flow in the lead sheaths, the current being proportional to the load. The correct precautions against this are by no means obvious. If the sheaths are insulated from each other there will be a considerable difference of potential between them in the event of a heavy momentary overload; in addition, there is always the danger of accidental contacts due to disturbance of the ground. Such contacts are dangerous, as they are in general of high resistance and would result in local destruction of the sheaths. On the other hand, if the sheaths are properly bonded together at intervals there will be a decided addition to the cable losses. I cannot agree with one statement that the author makes on page 58 in connection with core curvature, namely, that it is obvious a large current-carrying capacity will not be required in such high-voltage cables. First of all,

[illegible] I think one may confidently say that single-core cables will not be used where 3-core cables are possible, because of the engineering difficulties to which I have referred. This means that single-core cables will only be adopted when the working pressure is a great deal higher than any in use to-day. Such high working pressures will naturally only be required for long-distance transmission. Under such circumstances it would be uneconomical to transmit the small amount of energy corresponding to a small size of core. In such cases, it seems to me, very large amounts of energy would have to be transmitted, and comparatively large cores would therefore be required, so that in the majority of instances it is probable a cable of large radius would be used in actual practice. From this point of view, it seems to me that the utility of the inter-sheath cable amounts to this: it provides a means of transmitting small amounts of energy long distances. I doubt whether under those conditions it would have a very large application. On the other hand, the ordinary single-core cable does eventually reach a limit beyond which it cannot be applied on account of excessive diameter. In those circumstances the inter-sheath gives us a cable which can still be installed, but when these conditions are reached we are in the position of having to transmit extremely large amounts of energy over extremely long distances. I am doubtful whether such conditions will arise in this country. There is another difficulty, and I see that the author anticipates that this will be the real difficulty with these cables. Nobody could reasonably object to an inter-sheath cable if the inter-sheathing were the only alteration. Obviously, if the factor of safety of the cable could be improved by merely adding a copper tape between two particular layers of the dielectric, it would be done; but I fear that the methods which will have to be adopted for obtaining the voltage that has to be impressed on the sheaths will introduce troubles of their own. The sheaths cannot be regarded solely as serving to keep the stress of the working potential on the insulation below a certain value. They ought also to take care of the surge stresses. Without knowing exactly what the proposed arrangements are, I fear that so far as surging is concerned the conditions will become rather worse than without the sheaths. As is well known, exceedingly high voltages are often experienced on the end turns of transformers, and I do not know of any satisfactory method of impressing voltage on the inter-sheath without sometimes running considerable risk of a pressure, equal to or even higher than the normal working voltage, being imposed on the inner layer of insulation between the sheath and the core. This is a condition in which the cable would be much more liable to fail than if there were no inter-sheath. I do not say that it is impossible to get over the difficulty, but it is obviously a matter that requires careful consideration before the device is seriously applied in practice. In particular, some arrangement should be adopted whereby the behaviour of such a cable can be observed under surge conditions.

Professor Schwartz. Professor A. Schwartz: I feel sure we shall all agree that there are three main groups of properties which materials for the dielectrics of cables should possess. First, electrical properties such as insulation resistance and dielectric strength; secondly, chemical properties such as stability and inertness; and thirdly, mechanical or physical properties such as strength and durability. Further, I think we shall all agree that such dielectrics should not only possess these qualities in the initial stages of their life, but should also be able to maintain them over a very considerable period of years. The best method that I am aware of whereby we can to some extent forecast the duration of these properties lies in physical and mechanical tests, such as the bending, scuffing, abrasion and hysteresis tests. In connection with rubber cables, the author states that "The physical properties of vulcanized rubber are fairly well understood, and have received much attention from time to time, but efforts to co-ordinate them with electrical properties have not been and cannot be successful, at least in the present state of the art." With that statement I am quite in agreement, but I hope it will not be understood as meaning that at the present time we can afford to any extent to dispense with physical tests. The physical test is not used to determine electrical properties of the dielectric, but to give an indication of the degree of permanency which those electrical properties possess. If we have a number of samples of rubber compound, each of which complies with given requirements as to insulation, resistance, and dielectric strength, the best compound for actual service will be the one which is formed from the best grade of rubber: it will possess the best physical properties, and will be the most durable. In connection with the author's remarks in regard to the natural deterioration of rubber, I should like to state, as the result of a series of experiments which I carried out recently in conjunction with Dr. H. P. Stevens, and which extended over about forty months, that so far as the natural deterioration due to exposure to light, air, water, moisture, etc., is concerned, we find that the behaviour of plantation smoked sheet and plantation pale crepe compares favourably with that of fine hard Brazilian Para rubber, so that the rubber manufacturers have already reached the stage of excellence with plantation rubbers which the author thinks they may reach some time in the future. I was very interested also to notice that the author emphasizes the danger from the presence of sulphur in the layer of rubber next to the strand. In that position most of us would not expect to find much sulphur. There are, however, at least four sources from which sulphur may be introduced. First, sodium bisulphite is used frequently as a preservative for the rubber latex to the extent of about 1 part in 400 to 2,000 of latex, and although this amount does not affect deleteriously the insulating properties of the cable, yet it contributes to its sulphur content. Secondly, raw rubbers always contain a small quantity of sulphur united, Brazilian fine hard Para containing about 0·1 per cent. Thirdly, the rubber tape is frequently "cold-cured" in order to toughen it, and the sulphur content of 0·3 per cent which is sometimes specified as a maximum for the pure rubber layer may easily be exceeded from this source alone. Fourthly, sulphur may penetrate the pure rubber layer during the process of vulcanizing the cable. I am glad that the author has given us details of his valuable test for the character of the tinning, as it is of great importance that the copper should be efficiently protected from the action of the sulphur in the rubber and that the rubber should be protected from the action of copper oxide on the conductors.

Mr. F. C. RAPHAEL (*partly communicated*): This paper will [illegible] advance our knowledge of cable manu- [illegible] thanking the author we must also remember [illegible] presenting this paper to the Institution he had obviously a very attractive alternative before him, namely to keep this knowledge for the sole use of himself and his firm. Cable makers have been accused of adopting only rule-of-thumb methods, but the paper shows that this accusation is quite unjustifiable. The author's talent for painstaking investigation into detail is the same as that to which the Germans have been able to attribute their success in the engineering industries. In cable manufacture, however, Germany has learnt from us everything which she knows, and she has not even evolved more economical methods of manufacture. If German competition with us has been keen, it has been solely for two reasons. The first of these is that the majority of the buyers are not able to recognize the difference between good and less good cable—both have precisely the same appearance—and in consequence they are easily led to purchase the cheaper. In this connection I would urge British cable manufacturers to endeavour to find some better way of convincing engineers as to the quality of vulcanized-rubber cable and its probable life than that of merely labelling it with three letters which after all are no more than an abbreviated description of a group of firms. Some months ago I had occasion to draw up a specification for the re-wiring of a large building for which about seven miles of cable was required. The specification called for and described in unmistakable terms the very best cable for the purpose—a cable which all our leading manufacturers make for Admiralty and other wiring work of a very permanent character—stating also that it must be British made, and that the tender must be accompanied by guarantees that the cable fulfilled the requirements of the specification. Yet one of the contractors actually submitted a cheap German cable masquerading under an English braiding, and one or two others offered samples marked with the three mystic letters referred to without further guarantee. The other reason for the success of foreign cable in competition with British is that the foreign maker has apparently been content to take less profit when it is a question of equal quality. Passing from remarks of a general character, arising only incidentally out of the paper, to questions of detail, I would first refer to the inter-sheath cable. I take it that before using the conductor with the two lead tubes, shown in Fig. 3, the author has assured himself that under the severest conditions of overload there would be no possibility of the lead melting. The inter-sheath, however, might conceivably be affected in this way if a fault occurred due to slight mechanical damage, so that the breakdown was gradual. The author has a device for "anchoring" the inter-sheath at a fixed potential. At any time that it became necessary for this device to allow a large current to flow in order to keep the potential the same, it is quite possible that the inter-sheath itself might carry such a large current that there would be risk of the sheath melting. If, however, this device will not allow a sufficiently large current to flow to maintain the potential, and is purposely allowed to break down if there is too high a potential to make up, the intermediate sheath would assume earth potential, and there is then great risk of a breakdown between the core itself and the inter-sheath, since the thickness of the dielectric is halved. That produces a possibility of breakdown at several points on the cable, as there will be naturally a greater stress along the whole cable; and then, if the conductor sparks through to the sheath at two points there is once more the possibility of large currents passing along the inter-sheath and melting it. Again, in the case of a sudden breakdown one cannot rely, I think, upon the voltage between the inter-sheath and the core, and between the inter-sheath and the outer lead, being maintained up to a definite instant and then suddenly falling to zero. There is a possibility that one of the two halves of the dielectric will break down first, and, as before, we get the same effect of a high voltage between half the radial thickness of the cable and the possibility of breakdown at several places. This danger of a breakdown in several places is very important from another point of view than that of having to repair the cable here and there. Cables such as these, I gather from the author, will probably be run in long lengths with lead sleeves instead of disconnecting boxes. That means that as these cables are only to be used for long distances it will be necessary to carry out a localization test. It is possible with a cable like this, having a conductor of only moderate size, to localize a fault to within a yard per mile of cable; but if there are several faults, or even only two faults, the localization test is practically valueless, because it merely gives an intermediate position between the various faults, depending on their resistance. That is a very important point indeed, because these cables will have to be repaired quickly. In this connection the use of the split-conductor system will be very welcome, because, under present conditions, if a 3-phase cable burns out and the fault is allowed to develop considerably before current is switched off, as usually happens, the whole cable is often burnt right through, and the lead sheathing and the cores become joined together but do not make a perfect contact of very low resistance compared with that of the cable, although sufficient to render it impossible to localize the fault by a capacity test. As the core is burnt through the fault cannot be localized by a loop test or fall-of-potential test, and one cannot localize it like a dead earth on a telegraph cable because it is not an absolutely dead earth, owing to the resistance of the fault. Another point in connection with the inter-sheath cables of very large diameter which the author has described, is whether there would not be a liability for the lower flakes of a long cable to be flattened by the weight of the upper flakes when wound on a drum. This cable would not possess so large a resistance to compression as would a concentric cable of the same diameter, and if the circular shape were distorted part of the advantage of the large diameter conductor and of the inter-sheath might be neutralized. The metallic test sheath which the author says he has applied to ordinary lead-covered cables separated from the outer lead sheath by only a small thickness of insulation is a very good idea, for, with existing designs of extra-high-tension cable, a defect in the lead might well escape observation in the factory test and only show itself months or even years after the cable has been laid. To assist maintenance tests, however, I would suggest that the insulation resistance of 50 megohms per mile between the lead covering and the test sheath should

Mr. Raphael.

[illegible] high insulation is a sign of long-continued heating and [illegible] before, during, or after the application of the paper, but I [illegible] which I made rough condensers and tested them for capacity and insulation after various periods of drying at an even temperature. All these papers were tested in the natural state as they were received from the paper manufacturers and were not impregnated in any way. I found that after a certain number of hours' drying, some of the papers which had previously shown poorer electrical properties developed a far higher insulation resistance and lower specific inductive capacity than the others. In all these cases, however, the papers had become quite brittle, and if they had been used for cables they would have had precisely the properties after long-continued heating which the author attributes to super-saturation of the impregnating material. In describing the joints with porcelain spacers, the author has omitted to say how these are finished off. I take it that they are simply covered with a lead sleeve wiped on to the cables, which is then merely filled with insulating material. In considering the conditions affecting the life of vulcanized-rubber cables, the author briefly dismisses "the natural deterioration common to all rubber [illegible] is correct as to this, one would reasonably expect that the difference between the inferior and better grades of vulcanized-rubber cable would be in the thickness of the dielectric. This is not the case, however, for the author's firm, and in fact all the members of the Cable Makers' Association, supply exactly the same dielectric thickness for 300, 600, and 2,500-megohm grade cable. The only object in using a better-grade cable for ordinary low-pressure work [illegible] author is right, the better-grade cables should simply have [illegible] It is well known, however, that ordinary vulcanized-rubber cable firmly fixed in casing or drawn in iron barrel (so that in either case it is only the outside of the cable with which air can come in contact) becomes hard and brittle after a comparatively short number of years, no matter what is its [illegible] possible, but as it was not practicable to relay them they were no doubt left slightly damp. Since then they have [illegible] to condensation. Finally, I should like to refer to Professor Schwartz's recommendation of plantation rubber. I do not wish in any way to detract from the value of the tests to which he and Dr. Stevens have devoted seven months, but I would point out that a 7-months' test can tell us very little with regard to the relative lives of the two materials. The chief trouble with india-rubber, and the reason why it [illegible] purposes, is that it changes its character with age. Para rubber has proved itself in the past to be the most stable of any, both in its pure state and when compounded with other ingredients and vulcanized, and one is loath to take [illegible] rubber.

Mr. J. H. C. BROOKING: Dr. Russell stated that this was the first paper on the subject of cables which a cable maker had brought before the Institution. I should like to point out that a paper was written and read before the Manchester Local Section in 1905 by Messrs. Atkinson and Beaver,* and it is a remarkable thing that such a valuable [illegible] one or two points in connection with cable making that [illegible] not dealt with the question of the protection of cables, and at the present time the requirements for the protection of cables are becoming more and more important. One interesting point that the author has mentioned with regard [illegible] mentioned. One, which I [illegible] increased trouble due to the effect of vibration upon the [illegible] known. This is often caused by railway [illegible] Mr. Brooking.

* [illegible]

seriously damaged by it. In connection with the deterioration of rubber, the author refers on page 70 to "the natural deterioration common to all rubber goods." I have heard of a certain class of rubber which is used in connection with cable protection, and I should like to say that if the word deterioration is mentioned in regard to this sheathing material, then it should also be mentioned in regard to the Pyramids of Egypt. A further point made in the paper as to the physical properties of vulcanized rubber is that insulating rubbers do not show any alteration in insulation resistance when immersed in water. I have always understood that rubber-insulated cables were immersed in water for 24 hours previous to being tested, in order to make sure that they had not materially suffered from absorption during such immersion.

Mr. Sparks. Mr. C. P. SPARKS: I should like to make a few remarks from the point of view of a supply engineer, and to sum up what I consider to be the outstanding features of British cable practice. So far as general distribution is concerned, I consider that the pre-eminent features of British practice are, first, a solid lead sheath, and, secondly, a wiped joint. These two factors have been dominant in the success and reliability of our distribution systems. The author says little about jointing, but in my opinion this point is of the first importance. Amongst the most radical improvements that have been made in distribution systems of late years is the method which I believe Messrs. Merz and McLellan were the first to adopt, namely, the vacuum process applied to jointing. This process ensures that the wiped lead joint is thoroughly sound, and the cable being warmed and exhausted under vacuum the joints are readily filled; that is to say, there are no air bubbles left in the joint. From experience with that method of jointing it is possible with jointers of ordinary intelligence to produce joints on a 10,000-volt cable that will successfully stand a test of 90,000 volts. On page 68 the author advocates the use of joints with porcelain separators and oil. It may be that he has in mind very much higher pressures than I have contemplated, but I am certainly of the opinion that for normal pressures the general principle of making the joint as much like a reinforced part of the cable is the best practice. I think the mechanical weakness of the porcelain and the risk of air by absorption of the oil serious disadvantages, and I much prefer a joint made with carefully prepared insulating material. With regard to the grading of cables, in this country the distances and the power transmitted do not warrant, at all events in the near future, pressures of more than, say, 30,000 to 40,000 volts. In my opinion the reliability of a single dielectric which is free from the complication introduced by grading, is so essential that the extra risks involved by the suggested grading are unwarranted, at all events so far as practice in this country is concerned. With the higher pressures, the transmission is carried out by overhead wires, cables being only used in short lengths for end or intermediate connections. It therefore appears to me that the question of grading cable dielectrics can be relegated to the distant future. I am interested in the author's reference to the impregnation of insulating material apart from the cable. Of course great difficulty arises in thorough impregnation of large extra-high-pressure cables, but I was unaware that manufacturers were making cables on a large scale in which the paper insulation had been separately prepared and independently impregnated. Owing to the risk of air being entrained between the layers of the dielectric I should be glad if the author in his reply would state what are the electrical characteristics of such cables under test. As Chairman of the Wiring Rules Committee I am interested in the author's reference on page 67 to the question of temperature rise. The National Physical Laboratory carried out for the Wiring Rules Committee a very exhaustive series of tests. The Committee was dealing with the question of cables for use in factories and houses, and fixed a low limit of temperature rise, the tests only extending up to 50° F. This paper relates to temperature rises up to 75° F., which of course introduce new conditions. I should like to hear what the author considers the safe upper limit of temperature rise in practice for different classes of dielectric. It has been suggested that the Wiring Rules Committee would be prepared to consider a higher temperature rise, but they want assistance from the manufacturers before they feel justified in raising the limit. Great assistance is also expected from the Research Committee of the Institution. At the end of the paper the author apologizes for the length of the section dealing with bitumen cables, and adds: "The troubles referred to are not inherent in the type of cable, but are attendant on fault conditions which should seldom occur, and which would equally produce some kind of trouble on any other type of cable." I am in total disagreement with him there. I think the bitumen cable should be placed in a class by itself. Bitumen has proved a treacherous material in the past, and in my opinion it should only be used under special circumstances, which only occasionally arise.

Professor Morris. Professor J. T. MORRIS: On page 66 a series of tests is given with regard to the expansion of two lengths of cables. The cables, as was seen in the lantern slide, were laid on rollers, one end of the cables being fixed, and the other, as I understand, being free. Fig. 10 (Cable A) shows that the amount of expansion increased from the fixed end to a point at least two-thirds of the way along the cable. I should like to know whether the cable expanded to an even greater extent beyond that two-thirds point. At the movable end it is found that a contraction occurred. I understand that that is a contraction of the whole length of the cable. In the other half of Fig. 10, which refers to cable B, a similar considerable effect is produced at the two-thirds point, though of contraction. Can the author give a fuller explanation of the curious behaviour of that part of the cable near the movable end? In cables which have been heavily overloaded from time to time the lead covering becomes of concertina-like shape at the ends where it passes into the boxes. This proves that the lead must be shifting with respect to the copper conductors in the cable. Plumbers are familiar with the similar effect of lead pipes crumpling on the south wall of a house. Probably many members have noticed this crumpling of the lead in concertina fashion owing to the alternate heating and cooling of the pipes. Would it not be possible to fix the lead with respect to the copper at suitable intervals, having, of course, due regard to insulation requirements? This would probably get over the trouble due to the lead breaking down. I see that the author fully appreciates the need for absolute exclusion of air in power cables. The very large fall of pressure that

[illegible] a small air gap in series with another dielectric having a greater dielectric constant is not thoroughly appreciated by all engineers. [illegible] O'Gorman have pointed this out, but it is seldom that one finds it carried out completely in practice. [illegible] the variation of capacity with temperature of a number of different dielectrics. The measurements were made with continuous current. Can the author tell us whether the result would have been obtained if the measurements had been made with alternating current? I think it is quite possible that a considerable difference would be found under these circumstances. [illegible] and at the junctions of the series generators. [illegible] in connection with his scheme, but at the present moment I believe that the voltage used is not high enough to warrant the adoption of this arrangement.

Mr. G. L. Addenbrooke: [illegible] very largely from the chemical aspect, as distinct from the electrical aspect. In the work that I have been doing in connection with dielectrics, my difficulties have lately been chiefly of a chemical nature, and there is room for a great deal more work on this aspect of the question. [illegible] up to the breakdown point, and he also refers to a paper by Höchstädter, who says that there may be nothing to be seen under such circumstances. Both statements are to a certain extent true. Under electric pressure or electric field certain losses take place in a cable. If the cable is not of first-class manufacture and the pressure is [illegible] be four times as large, but actually, if with such a cable these losses are recorded by means of a wattmeter, it will be found that they are increased more than four times, and as we approach the breakdown point the ratio of the increase will be found to keep on increasing. Then there is another point. If we observe on a wattmeter what is occurring in a cable, and if we apply a certain pressure and wait until the wattmeter gives a steady deflection, on watching the deflection and maintaining the pressure constant, [illegible] will occur increasing with time. That is due to the fact that the energy dissipated in the cable disappears in the form of heat. Heat warms the cable, the dielectric has a very big temperature coefficient and being at the same time a bad conductor of heat: this leads to more loss, and the effect is cumulative. Again, as the pressure is raised, the more this cumulative effect [illegible] results in testing, at any rate at the higher pressures; some [illegible] such increase is a certain evidence of [illegible]

Mr. C. H. Wordingham: [illegible] the manufacturers to go fully into the matter and provide suitable tinning plant. Another very important point was that referred to by Mr. Sparks, namely, the great difficulty of ascertaining from manufacturers what is the limiting temperature for different classes of dielectrics. It is vitally important in some cases to use cables at a high current density, but we do not know what temperature is [illegible]

Mr. S. W. Melsom (partly communicated): [illegible] tion by myself and Mr. Booth, and in Fig. 11 he gives curves showing the temperature rises that can be obtained by experiment as compared with those that might be obtained by extrapolating our results. I think it will be understood that in making determinations of temperature [illegible] method on which cables may be laid. The obvi[illegible] laying and then to make the series of tests under standard conditions. These standard conditions must be as nearly as possible the same as practical conditions, and at the same time should be on the safe side as regard[illegible] I must also join issue with the author in regar[illegible] statement that the "slight difference in the test c[illegible] . . . does not account for the difference in the temperature rise." During a recent investigation made with cables suspended in air we found the greatest difficulty in obtaining consistent results owing to the large cooling effect of slight air draughts. Had the author taken precautions to [illegible] In the first place I should like to call attention to the fact that some mistake has been made in the calculation of the [illegible]

Mr. Melsom.

Heating of Cables with Current"* it was specifically stated (page 721) "that in certain cases—*i.e.* single rubber-covered cables in air and in wood casing and paper-insulated lead-covered cables, both single and concentric—the connection between cross-section and current density could be fairly represented by a formula of the type $i = K\left(\frac{D}{S}\right)^n$." On page 722 of that paper the constants for the various types of cable were given, and it was stated that "For concentric and twin cables the formulæ are the same as for lead-covered single cables if S, the total cross-section, is taken as being both that of the lead and the return conductors." Thus, in view of the fact that the investigations from which these formulæ were derived did not extend to 3-core cables, it was not even claimed that they could be successfully applied to such cases; but if they are applied, the results obtained will be very different from those shown in Fig. 12. In the absence, however, of any particulars of the dimensions of the cable used, it is not possible to do more than suggest an explanation of the discrepancy; but apparently the author has taken S, the cross-section, as being that of one conductor only, *i.e.* 0·1 sq. in., whereas, by proper analogy, the formulæ require that it should be the sum of the three, *i.e.* 0·3 sq. in. In the curves herewith (Fig. A) I give the values so calculated by this use of the formulæ, for a 660-volt and a 6,600-volt paper-insulated plain lead-sheathed cable. The dimensions of these cables were taken from Messrs. Glover's list, and either of them would, I presume, come within the definition given by the author—"moderately heavily insulated 3-core cable." The curves are calculated for a rise of temperature up to 50° F., thus:—

* *Journal I.E.E.*, vol. 47, p. 711. 1911.

Curve 1.—660-volt cable.

Cross-section, $S = 3 \times 0{\cdot}1$ sq. in. (3-core 0·1 sq. in.),
Outer diameter, $D = 1{\cdot}44$ in.,

$$D/S = 4{\cdot}8\ ;\ (D/S)^{0{\cdot}5} = 2{\cdot}19,$$

and using the constants given in our paper (page 722), the current density for a temperature rise of 20° F.
$= 429 \times 2{\cdot}19 = 940$,
the current density for a temperature rise of 30° F.
$= 536 \times 2{\cdot}19 = 1{,}180$,
the current density for a temperature rise of 50° F.
$= 688 \times 2{\cdot}19 = 1{,}510$.

Curve 2.—6,600-volt cable.

Cross-section, $S = 3 \times 0{\cdot}1$ sq. in.,
Outer Diameter, $D = 1{\cdot}740$ in.,
$(D/S)^{0{\cdot}5} = 2{\cdot}41$,

and multiplying this number by the same constants as for the 660-volt cable the current densities for temperature rises of 20° F., 30° F., and 50° F., are 1,030, 1,290, and 1,660 respectively. In both cases the values above 50° F. were obtained by assuming a square law, that is to say, $t \propto i^2$. As I mentioned before, however, it was clearly stated that the formulæ given in our paper applied only to cables under conditions such as would be met with in internal wiring. Mr. Beaver points out that the Institution figures do not apply to underground cables, and therefore no comparison ought to be made between my Curves 1 and 2 and the results obtained by the author with cables which were presumably laid in the ground. The main point of interest in the author's Fig. 12 is the large difference between the results that he gives as "from tests" and those obtained by other observers from Dr. Kennelly

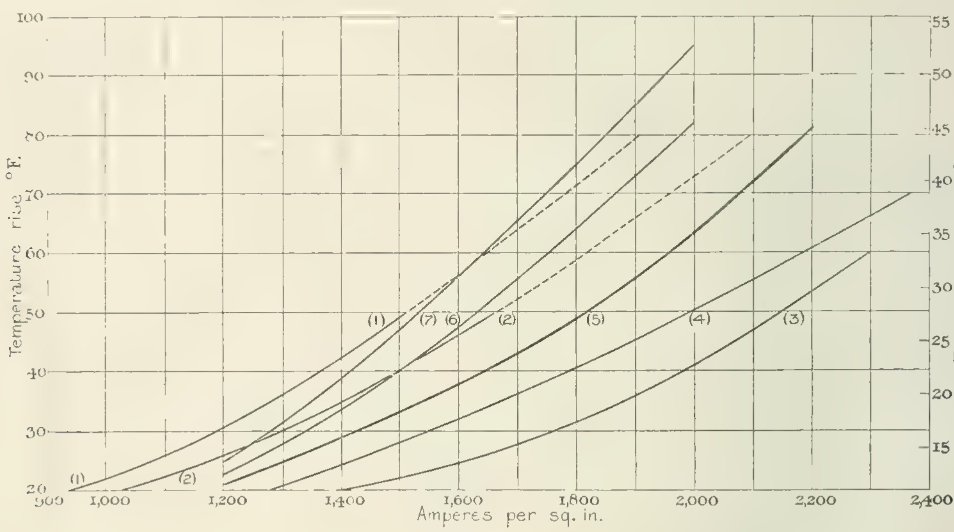
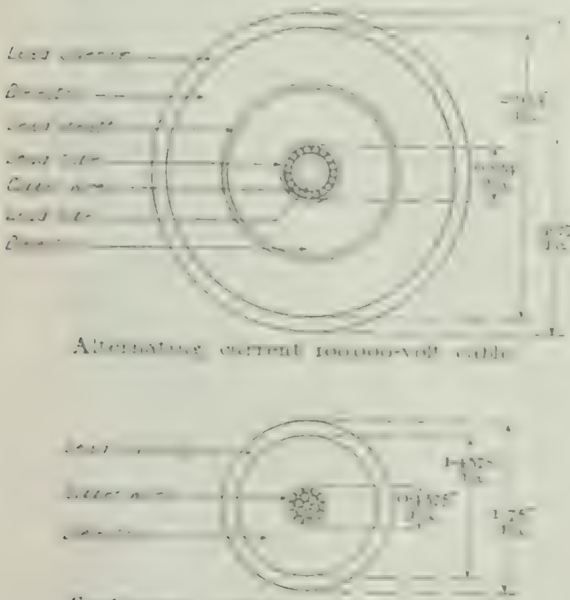


FIG. A.

(1) Lead-covered paper-insulated (660-volt) cable from formulæ (above 50° F. by assuming square law: $t \propto i^2$).
(2) Lead covered paper-insulated (6,600-volt) cable from formulæ (above 50° F. by assuming square law: $t \propto i^2$).
(3) Curve stated in Mr. Beaver's paper (Fig. 12) to be drawn according to formula $\left[i = K\left(\frac{D}{S}\right)^n\right]$
(4) 3-core 3,000-volt cable laid direct, by German (1907) tables.
(5) By Apt and Mauritius formula $\left[I = \sqrt{\frac{tQ}{c}}\right]$ as given by Mr. Beaver.
(6) From Mr. Beaver's test: Steel-armoured cable laid direct.
(7) From Mr. Beaver's test: Laid solid in wood troughing.

[illegible] The author quotes Messrs. Apt and Mauritius, but since Dr. Apt agreed some time after the publication of his results that the formula of Kennelly, as used by [illegible], was more nearly correct, a better comparison is given by Curve 3 in Fig. A herewith, in which I have plotted the values for a [illegible] cable laid direct in the ground according to the German [illegible] tables.* The matter is in view of the investigations now in progress on the heating of buried cables of great interest. A large number of tests are being made under [illegible] conditions, and it would be of very great assistance to the Institution Sub-committee if the author in his reply to the discussion would give fuller particulars of his tests, such as the dimensions of the cables, particulars of the coverings and their thermal constants, the depth at which his cables were laid, the amount of moisture in the soil, the time over which the tests extended, the apparatus used, and the methods of observation.

Mr. J. S. HIGHFIELD (*communicated*): I am particularly interested in the author's description of the work that has been done on single-core cables for very high pressures. It will be very interesting to see what practical progress is made in the next few years with inter-sheath cables. It appears to me that the 100,000-volt cable illustrated in Fig. 6 must be a costly cable to manufacture and, owing to its large diameter, to lay and properly protect. Without knowing the actual cost it is impossible to reach any



Alternating current 100,000-volt cable.

Continuous current 100,000-volt cable.

FIG. B.

definite conclusion as to the probable extent of the use of these cables, but I think that except in very special circumstances where the amount of power and the distance to be covered are unusually large, such cables will not be used except to connect up overhead lines. It seems to me that in such cases as the above the supply should be given by means of overhead mains, and that if underground cables are necessary, a continuous-current supply would produce [illegible] [illegible] current. The difficulty of [illegible] for [illegible] current as compared with continuous current [illegible] be [illegible] from the accompanying diagrams (Fig. B), one of which is a half-size reproduction of the cable shown in Fig. 6, and the other a half-size section of a single-core continuous-current cable, both cables being designed to work at 100,000 volts, the first with alternating current and the other with continuous current. I am surprised to notice that the author refers to copper as "the only metal that [illegible]." Aluminium [illegible] [illegible] cables [illegible] a large scale. I myself have used it for low-tension work both as single core and also in the form of triple-concentric cables. Of course a soldered joint cannot be made, but I have found no difficulty in making a good mechanical joint [illegible]. The [illegible] [illegible] of the [illegible]. At the present [illegible] low-tension aluminium cables with cores of half an inch and upwards are about 20 to 25 per cent cheaper than the equivalent copper cables. They are also somewhat easier to handle than copper cables owing to their smaller weight. I have worked out no figures, but in cases where it is necessary to increase the areas of the cores of high-pressure cables for electrostatic reasons, as described by the author, I think in all probability aluminium would be cheaper than copper, as the greater bulk of the metal would be an advantage and might obviate the use of the lead core.

Mr. E. [illegible] (*communicated*): The author has confined his paper almost entirely to the consideration of cable dielectrics, the core itself not receiving much attention. Formerly, the only available material for the core was copper, but a serious rival has now arisen in aluminium. On page 58 the author states that for pressures of 50 to 100 kilovolts the size of conductor is fixed by the formula $r = V/S$, where V is the working voltage, S the permissible maximum stress in the dielectric, and r the radius of the conductor. For a given value of r an aluminium conductor will have a conductor weighing but one-third the weight of the copper cable with the same value of r, and consequently, since the cost of the dielectric will be equal in both cases, the cost of the aluminium cable should be much lower than that of copper. For instance, with copper wire at the present price of 7¾d. per lb. and aluminium at 11½d. per lb., there would be a saving of 50 per cent on the cost of the core, and it must be noted that the price of copper is very low. Applying this to the cable shown in Fig. 3, page 59, the saving on the core will amount to about £47 per mile. If, on the other hand, it is desirable to have equal conductance in both cases, then, as is well known, aluminium having but 60–61 per cent conductivity compared with copper, its diameter will be about 29 per cent greater than that of copper of the same conductance. In this case, however, the weight of aluminium will be half that of copper, giving a saving of only [illegible] per mile. [illegible] reckoned, however, the saving on the smaller size of lead core (referring to the cable shown in Fig. 3, the type preferred by the author). Keeping the same outer radius for the core, the aluminium equivalent will be 12/0·147 in., giving the inner lead tube a diameter of 0·400 in. [illegible]

* [illegible]

7

Mr. Driver. reasons require the same ratio of internal to external diameter of the lead tube, the bore will now be 0·194 in., so that taking lead at £18·5 per ton there will be a saving of £16 per mile on the lead, or a total of £37 per mile on the complete cable, since the dielectric is the same in both cases. With cables for low voltages the area of the conductor is calculated more from a consideration of the transmission and distribution economy than from dielectric stress. Consequently the cross-section of an aluminium core must be based upon an equal conductance to a given copper core, with the result that as above mentioned the diameter of the aluminium core will be about 29 per cent greater than that of the copper core. The core itself will be much cheaper than the equivalent copper core, but the cost of the extra insulation, owing to the increased diameter, will offset this saving to some extent. It must be borne in mind, however, that for a given dielectric stress in both cables, the greater diameter of the aluminium core necessitates a thinner dielectric than would be necessary for the copper. Thus the extra cost of the dielectric is not so great as would appear at first sight, and in all cables of section over, say, 0·1 sq. in., aluminium should show a distinct economy over copper cables of a similar class. This saving, of course, becomes more apparent the larger the cross-section of the core, as the cost of the conductor is then a greater proportion of the total cost of the cable. Hence low-tension railway feeders and similar cables offer every inducement for the employment of aluminium. As an example, a recent aluminium paper-insulated double-lead-covered low-tension cable of 1·3 sq. in. cross-section showed an economy of 14 per cent over the equivalent copper cable, or about £115 per mile. In the footnote on page 71 the author passes somewhat lightly over an important point. The fact that rubber and similar materials have no action on aluminium obviates the extra cost of tinning required in connection with copper cables. Moreover, with this class of insulation, the tendency for the core to decentralize is very considerably decreased, since the intensity of the mechanical pressure on the dielectric is with an aluminium core only two-fifths of that with a copper core of equal conductance. The ratio of tensile strength to weight for equal conductance is 2·73 to 1 for aluminium and copper, which, making due allowance for the weight of the extra insulation with the former cable, still leaves a considerable margin in favour of the lighter metal, thus rendering the handling and the installation of such cables for mine work much easier and cheaper, and the cables themselves much stronger. The heating of cables is mentioned by the author, but again no mention is made of aluminium cables. The greater diameter of the latter gives a greater radiating surface, with a resultant lower temperature rise for any given load. Thus for any specific rise of temperature (which is the limiting factor in many installations) it is possible to work aluminium cables at a relatively much higher current density than is the case with copper. Experiments show that an aluminium cable of equal conductance to a given copper cable will carry about 14 per cent more current than the latter with the same rise in temperature. Conversely, calculating the section on considerations of temperature rise, an increase of 42–45 per cent in the section of a copper cable will place the two cables on an equal basis, instead of the 64–66 per cent rendered necessary by considerations of conductance. This will still further increase the economy of the aluminium cable. A disadvantage of aluminium is its higher temperature coefficient of expansion, but, as the author points out, expansion is only of consequence at bends and joints, and careful attention to these points during installation should cause no trouble from this fact. On the whole it would therefore appear that the subject of aluminium cables should not be overlooked by engineers responsible for the installation of cables of any description.

Mr. Beaver. Mr. C. J. BEAVER (*in reply*): I attach a very high value to the remarks which Dr. Russell has made on the first part of the paper dealing with the inter-sheath type of cable. I feel that appreciation from him is appreciation indeed, because he is the founder of most of the conceptions on which all work of this type is based. I am also gratified to learn of his conversion to the inter-sheath type of grading, and to know that this was due to Mr. L. B. Atkinson, to whom I am indebted for much direct and indirect help and encouragement. Dr. Russell's remarks in regard to capacity or charging current have a vital bearing on the practical utility of the inter-sheath type of cable. It may be of interest in connection with his statements as to the distribution of the capacity current in the component parts of the cable to mention the currents at the working pressure of 100 kilovolts, 50 $\sim$, for the cable illustrated in Fig. 6.

Charging current per mile	(*a*) in conductor ...	3·9 amps.
	(*b*) in inter-sheath ...	7·4 amps.
	(*c*) in lead sheath ...	11·3 amps.

Dr. Russell referred at some length to the limitations of length which are imposed by considerations of the permissible capacity current, and to the method explained to him by Mr. Atkinson for feeding the capacity currents into the cable at intervals. In this connection it may be interesting to note that the thin lead inter-sheath shown in Fig. 6 will safely carry the charging current necessary for more than three miles of that cable when such current is fed from one end only. When fed from both ends this distance would be doubled. In alternating-current cables this feeding of capacity currents at intermediate points on long lengths could be conveniently accomplished by compensator coils connected between the main conductor and the lead sheath, each tapped at a suitable point for connection to the inter-sheath. Naturally, however, the use of such cables will be restricted—at least for a long time to come—to places where it is absolutely necessary to use insulated cables in conjunction with bare overhead lines; for instance, in station connections or en route in a transmission line; so that the consideration of intermediate feeding is perhaps in the nature of a glimpse into the distant future.

In reply to Mr. Rayner, the inter-sheath type of cable is not yet in use anywhere, but it has satisfactorily passed through the difficulties of the manufacturing stage of its existence. The form of hollow conductor illustrated in Fig. 3 has been used, and is regarded as a preferable construction for the following reasons:—The inner lead tube affords a smooth cylindrical surface on which to strand the copper wires. The outer lead tube offers a smooth surface to the dielectric in place of the serrated surface of the copper conductors. The electrical

[illegible] known.* [illegible] very detrimental.

[illegible] of the intermediate sheaths, the most convenient method [illegible]

[illegible] did not intend to convey that the increasing values of [illegible]s current shown by Mr. Rayner's experiments [illegible]ctly due to alterations of the capacity of the [illegible] would have been absurd. [illegible] and Mr. Rayner, and contrasting them with those of [illegible] effect of temperature on the capacity of the dielectric, [illegible] dielectric. The point which I tried to convey was that the properties of different insulators possibly had some bearing on the divergence of results obtained. I can assure Mr. Rayner that the test conditions and the insulation-resistance values of the material at even the higher temperatures were such that it was impossible for Curve 1 [illegible]

I am afraid that the information asked for by Mr. Rayner as to the components, proportions, and properties of insulating materials used in cable manufacture would entail a separate paper, which would hardly be of general interest. Much of it has already been published, though perhaps not in the collated form which Mr. Rayner desires.

I should like to correct the impression which Mr. Hunter appears to have gathered, that the paper recommends single-core cables for more or less ordinary pressures. The limiting factor of 3-core construction will be the diameter of the cable, and references to single-core construction will therefore only apply to 50 to 100 kv. cables. The single-core inter-sheath cable shown in Fig. 6 illustrates this point. The cable is just over 3 in. in diameter, and is designed for a working pressure of 100 kilovolts. It is perhaps larger than would ultimately be used, being designed with a factor of safety [illegible]

I am very glad to have Mr. Hunter's practical criticism of this cable from the user's point of view. From what I [illegible] In any case the [illegible] the co[illegible] which [illegible]

I quite agree with Prof[illegible] between materials, especially if—as is the case [illegible] they are [illegible] can yet be relied upon to give r[illegible] able from hard fine Para in commercial practice, although, as stated in the paper, such equality will no doubt be ultimately attained. That I am not alone in my opinion is evident from the fact that raw hard fine Para costs several pence per pound more than the best grades of plantation rubber, in spite of the fact that it contains—and therefore loses during its preparation for use—nearly 20 per cent of [illegible] plantation rubbers.

With regard to the difficulty of distinguishing with certainty between "good" and "less good" rubber-insulated cable, I can assure Mr. Raphael that nobody would more [illegible] between them than the British cable maker. T[illegible] remains, however, that the only meth[illegible] reasons is of restricted practical use, or reliance on the recently introduced practice of identification by having the manufacturer's name printed on the tape. An intermediate course is to adopt a specification which will take care of a few vital points that are capable of being checked by a few simple operations. It is [illegible] this course is only open to large u[illegible] knowledge that most specifications of this kind are capable of being complied with in the letter and evaded in the spirit by an unscrupulous manufacturer. Mr. Raphael has rather misinterpreted my general statement as to the superficial action of all the types of deterioration referred to in the paper. No reference was made to [illegible] British cable, with all other c[illegible] ness would last longer than a [illegible] deteriorating influences were superficial in t[illegible] therefore in their primary effects. It is ob[illegible] as the surfaces become affected, they resist the deteriorating

* [illegible] † [illegible]

Mr. Beaver. influences less, and consequently the action penetrates further. The complete change to a hard and brittle consistency in a short time to which Mr. Raphael refers may, in a cheap foreign cable, simply mean that the chief deteriorating influences are unsuitable ingredients in the rubber, such as rubber "substitutes." This, however, along with questions on the relation of "grade" to life, and the behaviour of rubber under bad conditions of installation, are rather outside the scope of the paper.

Mr. Raphael's anticipations of risks in the practical use of the inter-sheath cable at high voltages are largely based on the assumption with which I have already dealt, namely, that very long lengths would be used. From my replies to previous speakers it will be clear that the inter-sheaths normally only carry charging currents, and that there is no likelihood of melting them under such conditions. As regards the condition of breakdown or incipient breakdown, he has apparently not had in mind the use of protective devices, such as the Merz-Price-Hunter, which would most certainly be used. Nor does he apparently appreciate that the cable illustrated in Fig. 6 is designed at such a low maximum stress that half the dielectric would support the total working pressure for a considerable time at least, so that a total breakdown would be a rather remote contingency. In addition, there is the valuable feature mentioned in the paper, that the individual sections of the dielectric are capable of being separately tested, which must constitute a considerable safeguard against any incipient tendency to breakdown. In reply to Mr. Raphael's question as to the tendency of the inter-sheath cable to flatten on the drum, my experience with 150-yard lengths shows that such tendency is practically absent. It must be remembered that the conductor is specially made non-collapsible, as shown in Fig. 3, and that the paper layers are tightly wound on and the outer lead sheath closely applied. I am glad to have Mr. Raphael's approval of the "test sheath" described in the paper, and in reply to his warning as to its thickness, would inform him that the thickness used is such as practical experience has demonstrated to survive not only manufacturing operations, but also the severest methods of laying, including drawing into ducts by traction engines, and hauling across rivers by steam winches. The sheath is usually in the form of a copper tape.

With regard to Mr. Raphael's remarks on the subject of overheating paper and its effect on electrical properties, my own early experience in the manufacture of dry-core cables tends to confirm his. In fact, my original draft of the paper contained the following sentence: "True, the case of the dry-core telephone cable appeared to lend colour to the idea, but . . . it is doubtful whether any undeniable proof was ever established." My own theory was that the decomposition of the fibrous structure which undoubtedly occurred caused shrinkage and less-continuous contact of the fibres and of the paper surfaces, and consequently led to alterations in the apparent electrical values which were not due to the material *per se*.

In reply to Mr. Brooking, the matter of mechanical and chemical protection of cables has received so much attention elsewhere, that it seemed superfluous to deal with it in the paper. With regard to his question as to the insulation resistance of rubber-insulated cables, my point was that high-grade rubber dielectrics designed purely for electrical properties will show practically the same insulation resistance on re-test after a further 24- or 48-hour immersion as after the first 24-hour immersion, whereas dielectrics of similar grade as regards rubber content, but very slightly modified as regards vulcanizing ingredients (with the object of attaining maximum physical properties), will show a considerable fall in insulation resistance under similar conditions of test. The reasons for this difference are discussed in the paper. Mr. Beaver.

I note that Mr. Sparks is in agreement with me as to the general desirability of making joints in lead-covered cables as much like a specially reinforced part of the cable as possible, but that he does not follow me to the extent of eliminating the element of variable workmanship by the use of porcelain separators in the place of insulating wrappings. I can only say that the type of joint illustrated in Fig. 14 has been evolved by a process of elimination of features which a long series of experiments have shown to be undesirable. In my experience, pressures of 50 to 100 kilovolts necessitate different details of design from those which are good enough for lower pressures, on account of concentration of electrostatic stress combined with the possible existence of weak paths along wrappings of insulating materials. With regard to the filling of joints by the vacuum process, I abandoned both vacuum and pressure processes several years ago in favour of filling under atmospheric pressure by means of a jacketed funnel left in position and kept warm during the cooling down of the joint. The head of hot compound in the funnel ensures that all gases or trapped air are expelled during the cooling process, whereas a vacuum tends to produce gases, and pressure is liable to cause them to be occluded.

I quite agree with Mr. Sparks that very high-pressure transmissions will be carried out by overhead lines; I would go further and say that when in conjunction with such lines it is necessary to use insulated cables, the alternative of stepping down to voltages which will not necessitate the use of graded cables will be seriously considered. At the same time I would point out that pressures of 100 kilovolts have been recently referred to by Messrs. Merz and McLellan in their Report on London Electricity Supply, and by Dr. Klingenberg in his address to the Institution last year,* as being already within commercial range. It is, I think, made clear in the paper that grading of some kind would be necessary under these working conditions, and also that the inter-sheath method of grading provides the best practical solution of the insulated-cable difficulties appertaining thereto.

In reply to Mr. Sparks' questions as to the impregnation of paper before application to the cable, I evolved this method some 17 years ago for reasons which had reference to uniformity of impregnation and general precision in manufacture. It has given perfectly satisfactory results ever since. The electrical characteristics are quite equal and in some respects superior to those obtained by the more common method of impregnating the whole cable after application of the paper.

With regard to the limits of temperature rise, to which Mr. Wordingham also made reference, my view is, as

* G. Klingenberg. Electricity supply of large cities. *Journal I.E.E.*, vol. 52, p. 123, 1914.

[illegible] d by ballistic methods, this has [illegible] paper in connection with Fig. 9. He [illegible]

I fully [illegible] room for [illegible] electrical pr[illegible] economy is attainable.

[illegible] m, my point in connection with [illegible] current-density figures. Two [illegible] paper. [illegible]

With [illegible]

[illegible] dielectric hysteresis. T[illegible]

[illegible] the economic aspect of cable work. [illegible]

Mr. Beaver. discussed elsewhere my view is that the question of the use of aluminium as a conductor for insulated cables may be left to settle itself automatically as economic and practical considerations dictate.

Manchester Local Section, 17 November, 1914.

Professor Marchant.

Professor E. W. Marchant: In the past the complaint has sometimes been made that cable makers will not give any information in regard to defects in cables, and particularly about the methods of overcoming defects. This is not true, however, in the present instance. The author points out what defects are likely to occur in a particular cable, and he even goes so far as to explain how a great deal of the trouble that is sometimes experienced with a vulcanized-bitumen cable can be avoided. With regard to the dielectric stress in a high-tension cable, the author states at the beginning of the paper that, to get the best results, the ratio between the outer and inner diameters should be ϵ, the base of natural logarithms—that is to say, the outer diameter should be approximately 2·72 times the inner diameter. The author no doubt knows, but I think it is not general knowledge, that under those conditions there is no possibility of a corona being formed in the interior of the cable. If we consider a concentric cable with a very thin core in which the ratio between the outer and inner diameters is greater than 2·72, we find that by increasing the diameter of the inner core we diminish the maximum stress on the dielectric of the cable. That leads to this result, that if the innermost part of the cable, that is, the part round the inner core, where of course the dielectric stress is greatest, is broken down, the effect of such breakdown is to destroy the dielectric and to form what is equivalent to a cable of larger diameter, so that there will be less stress on the dielectric than in the case of the core with the smaller diameter. Such a cable, when a corona has been formed, would not last very long, as the chemical products formed by the corona discharge would very probably attack the remainder of the dielectric. I should like, however, to ask the author whether there has been any indication that the breakdowns described on page 63 were not due to the formation of a corona inside the lead-sheathed cable. Another point is the electrolytic action that sometimes takes place when bitumen cables break down. I have before referred to a case which came under my own observation some years ago in connection with a bitumen cable. The negative cable broke down; the friable substance, which the author referred to as occurring round the joint, had, intermingled with it, a considerable proportion of pure sodium and potassium mixed up with caustic potash and soda, drawn in by electrolysis from the surrounding soil, with the result that the earth near this negative cable became very much overheated and the whole section had to be replaced. The experiments by Höchstädter described on page 64 confirm the results obtained by Mr. Holttum* at Liverpool University, viz. that there is not much fatigue in such dielectrics as ebonite. In these tests the material was subjected to an alternating stress for a definite period, and then, by means of a special switch, to a much higher pressure for about five alternations, the latter pressure being raised gradually until breakdown occurred. The dielectric strength, measured in this way, fell off slightly when the fatigue pressure approximated to the breakdown pressure, but the result was not very marked.

* W. Holttum. The nature of dielectric fatigue. *Journal I.E.E.*, vol. 50, p. 755, 1913.

Mr. Welbourn.

Mr. B. Welbourn: The synopsis at the commencement of the paper is very useful for reference, and the value of the paper would be further increased if the author would add a bibliography at the end. It is distinctly a manufacturer's paper, but it raises a number of questions of interest to the user, and it is from that point of view that I propose to discuss it. On page 58 the author suggests that the dielectric thicknesses fixed in March 1910 by the Engineering Standards Committee for 6,000 to 11,000-volt cables should be reconsidered. This subject has been much discussed by the manufacturers and users of cables during the last two or three years. In my reply to the Newcastle discussion on the paper which I read a short time ago* I dealt with the question to some extent. I think that so much progress has been made during the last few years in the manufacture of paper-insulated cables that it would be safe to re-design on a scientific basis all the cables mentioned in the British Standard Specification. Perhaps I ought to qualify this statement. It is quite safe to reduce the thickness of the dielectric so long as care is taken that the cables are used only on modern electric supply systems—that is to say, systems in which it is possible to rely on the voltage having a sine wave-form; but it might be unsafe in the case of a system supplied by alternators installed say 10 years ago, and having a wave-form with a pronounced peak which would be liable to set up resonance. Bearing in mind that the cable maker does not wish to restrict the use of his cable to certain supply systems, it will probably be advisable to retain the thickness specified by the Engineering Standards Committee, but to install the cables with the idea that some day it will be possible to raise the working pressure when the load has increased and new conditions arise. In connection with Fig. 6 the author discusses single-core cables for working pressures of 75,000 to 100,000 volts and a 3-phase transmission. I think there is no doubt that it is quite possible to construct single-core cables for these pressures. I remember that Dr. Klingenberg suggested in his address† last year that 100,000-volt single-core cables might be used for the supply of power to London, say from a coal-field in the Midlands. I should like to ask the author whether in suggesting high-voltage single-core cables he has considered whether it is commercially justifiable to use them at the usual frequencies of 25 to 50 cycles per second. As the result of some calculations which I made in connection with Dr. Klingenberg's suggestion, I came to the conclusion that the charging currents would cause such a large amount of plant to be idle that the proposition would not be practicable. The author says that the inter-sheath method is not commercially justifiable below 50,000 volts. That, I think, raises the

* B. Welbourn. British practice in the construction of high-tension overhead transmission lines. *Journal I.E.E.*, vol. 52, p. 177, 1914, and vol. 52, pp. 317–8, 1914.

† G. Klingenberg. Electricity supply of large cities. *Journal I.E.E.*, vol 52, p. 123, 1914.

[illegible] into account the cost of transformers, switchgear, etc., on [illegible] paper-insulated lead-covered cables will only be due to [illegible] after [illegible] cables, 8 years' experience of 20,000-volt 3-core cables, and 3 years' experience of 30,000-volt 3-core cables. Further experience is required as to the effect of the long-continued application of pressure to paper-insulated cables worked in the modern way at high temperatures. After Mr. [illegible] this point, e.h.t. cables being worked far beyond their ordinary stresses and at high temperatures, and it was satisfactory to find that after two years the paper had only deteriorated very slightly. The advisability of raising the working temperature of cables beyond 150° F. is rather doubtful. There is a disposition in some quarters to work 3-phase e.h.t. cables permanently at a tempera- [illegible] breakdown stress of about 200,000 volts per cm. I should like him to amplify that statement by mentioning the time element, because later in the paper on page 63 he mentions tests of half an hour's duration. I think he will agree that it is necessary to mention the [illegible] useful purpose. A modern 3-core paper-insulated cable can almost be tied into knots without in any way damaging the paper. The most remarkable case of that kind of which [illegible] working [illegible] out, and I was not satisfied until I got a joint which would stand a pressure of 100,000 volts, 60 cycles, for an hour without breakdown, and would then stand [illegible] nearly four years, and I a[illegible] support the author's conde[illegible] I agree with the author that the chemical corrosion of lead [illegible] occurred there was [illegible] A new cable was laid on the solid system and [illegible] trouble has since occurred. I am glad that the author calls attention to electrolytic corrosion. In the early days of lead-covered cab[illegible] that point, and I hope that the author's re[illegible] would [illegible] suggest to the author that he [illegible] nt; it is [illegible] predetermined points. I would also call [illegible] liable to alter in position, and it is just as necessary to

[illegible]

examine the electrical conditions of the network from time to time, say once a year, as it is to overhaul more frequently the pillars and boxes.

Mr. S. L. Pearce: The paper has been written by an expert in cable manufacture and can therefore be more fittingly discussed by manufacturers, but there are a number of points that appeal to the user. On page 58 the author makes some very interesting remarks with reference to the commercially economical size of cable that can be used for a working pressure of 20,000 volts. That information has been supplemented with some very useful data by the last speaker. As an engineer who has to deal with a large and increasing power load I should like to plead for the use of cables with larger sections than 0·15 sq. in. In connection with the new power station of the Manchester Corporation I have had to go very closely into this matter, and I think I am justified in using a cable of 0·25 sq. in. section at a working pressure of 33,000 volts. From the figures that have been put before me I am satisfied that such a cable is the most economical and commercial. Of course the calculations were based on the assumption that the cables will be more or less fully loaded. With regard to the question of grading, it would appear from the author's remarks that there is very little to be gained by attempting to grade cables when a working pressure not exceeding 50,000 volts is contemplated. I feel very much in the position that Mr. Sparks apparently found himself in when Dr. Russell's paper* was discussed, viz. that engineers preferred to use a single dielectric material that had been fully tested in practice. Nevertheless, the author makes various interesting suggestions, the chief of which is that the inter-sheath should be in the form of a lead tube. Reference has been made to the severe treatment that the cable receives in the bending tests. Whilst admitting that the cable is not treated in that way in the normal course of manufacture and use, it nevertheless receives a considerable amount of bending especially in manufacture, and I should like to ask the author whether he thinks it probable that the lead sheath will in time become wrinkled, in which case an inter-sheath formed of a copper braid might be preferable. The various suggestions and patented processes for conveniently anchoring these inter-sheaths are ingenious, but from the point of view of a supply engineer they seem to introduce complications, and they do not appeal to me. Dealing with the maximum stresses in high-voltage paper-insulated cables on page 61, the author seems to suggest that the existing methods of testing cables at $2\frac{1}{2}$ to 3 times the working pressure should be retained. Does he think that would be done in the case of cables for a working pressure of 40,000 to 50,000 volts? So far as the Board of Trade have issued regulations up to the present time, all that they ask for with cables at a working pressure of more than 10,000 volts is a test pressure 10,000 volts higher than the working pressure. When we have reached the stage at which working pressures of 40,000 to 50,000 volts are called for, supply engineers ought to be content with a test pressure of something less than $2\frac{1}{2}$ to 3 times the working pressure. On page 62 certain conditions are mentioned which call for grading. In clause (*c*)—where cable diameters would exceed say 3 in.—the author is presumably referring to single-core cables and not to multicore cables. With regard to the time element in connection with the pressure tests on page 63, my experience is that if a cable stands the test for five minutes it will not break down in half an hour. There does not seem therefore to be very much advantage in prolonging the test. The author's suggestion for testing the integrity of lead sheaths is excellent; for example, it would enable us to test our cables whilst these are in use; but I think an insulation resistance of 50 megohms per mile is altogether too low. On page 66 we have what I think is probably the most interesting point in the whole paper, and one which is of prime importance to supply engineers at the present time, namely, the movement in cables consequent upon expansion and contraction due to temperature variations. Of course there are numerous opinions on this matter. Some engineers would say that everything should be anchored, the joints as well as the lengths of the cables, so that no movement can possibly take place. There is another school, the adherents of which advocate the joint being anchored and provision being made for the cable to be laid in a wavy form so that expansion can thereby be taken up. The author's tests are, I must say, somewhat surprising. They seem to show that expansion joints, so far as regards providing for expansion and contraction due to temperature variations, are of very little use. That, I gather, is the conclusion to which the author has come. Flexible joints must, however, be exceedingly useful in the case of underground subsidence, but these tests seem to show that whilst this "flexibility" at the joints will protect the joints, it is still possible for damage to be done along the length of the cables. I believe the author holds the view that damage may arise through the rubbing together or the relative movement of the cores. I should like him in his reply to elaborate that point because it is a little difficult to grasp why there should be any relative movement of the cores assuming all three phases are equally loaded. I should also like him to define what he means by the expression "grossly overloaded." That is the crux of the whole matter. Does he advocate a return to the old rule, which was more or less a standard, of 1,000 amperes per sq. in.? In Fig. 15 the author illustrates some porcelain spacers. I have had no experience of this method, and I think other cable manufacturers state that porcelain is always a weakness. At any rate the same object can now be attained by using paper packing. The author has shown on the screen a series of lantern slides representing the damage done to a length of cable in Manchester. It illustrates very forcibly what we may expect to happen where there is a great deal of very heavy road traffic. The samples were not 0·5 sq. in., but 1 sq. in.; possibly that gives additional emphasis to the point which the author makes. On page 74 the author refers to the Board of Trade Report and the action of coal gas on vulcanized bitumen. I was one of the witnesses, and I think there is no doubt that some confusion existed in the minds of the Committee. If the bitumen filling is attacked by the action of coal gas—and the author does not dispute it—something else will soon come in to destroy the cable. A great deal can be said upon the question of vulcanized-bitumen cables. They undoubtedly have good points as well as disadvantages.

* A. Russell. The dielectric strength of insulating materials and the grading of cables. *Journal I.E.E.*, vol. 40, p. 6, 1908.

[illegible] would not have gone to the trouble of designing and [illegible] regards the deterioration of paper. It is evident that the British manufacturer uses every care in the selection of [illegible] impurities; can we say the same thing of the paper cables which have been brought into this country? At one time [illegible] what the paper was made of; and that the important material was the oil. If that theory of Continental [illegible] impregnation *in vacuo* after application and of using plenty [illegible] was not aware that cables had been deliberately allowed to [illegible] the Vernier joint would stand under such conditions. Mr. Welbourn mentions that these joints have been very [illegible] be satisfactory in the case of solid systems where the [illegible] or paper for insulating very high-pressure cable joints. I can quite see that Mr. Welbourn might be very [illegible] that the author's suggestions are made with the idea of [illegible]

[illegible] intended for very [illegible] The idea of non- [illegible] pressures, thus obviating the use of solder and [illegible] eliminating human errors altogether? I am [illegible] the emphasis which the author has laid on the [illegible] but a plumber's wipe is satisfactory. For [illegible] cables there are various satisfactory forms [illegible] cone connectors which give [illegible] is paid to [illegible] quantity of turns that I need not further refer to this point. In [illegible] material, and for this country is [illegible] on account of difficulties [illegible]

Mr. [illegible]

[illegible]. I think that insufficient attention is frequently paid to the laying of cables. A dry trench and dry material are essential for successful work, especially when cables are laid on the solid system in wood troughing. The proper filling of the trough is a difficult matter unless it is thoroughly understood. At bends the cable will always tend to expand during the process of filling the trough, and the bends should therefore be left until the remainder of the compound has set. Finally, the bend should be made to fit the cable, not the cable made to fit into the trough.

Mr. Allcock.

Mr. H. Allcock: In the first place it appears to me that we have here ample demonstration of the fact that British cable makers have long since discarded rule-of-thumb methods, and I should like to support the view expressed by Mr. Addenbrooke in London last week to the effect that in Mr. Beaver's work we have an excellent demonstration of the advantage gained by bringing expert chemical knowledge to bear upon what may appear at first to be purely electrical problems. For instance, in dealing with the question of graded cables, the author shows that it is preferable to employ one material for the dielectric instead of a number of materials of varying capacities, because in the latter case the life of the cable may be reduced by chemical reactions. With regard to the method of impregnating the paper before, instead of after, its application to a conductor, we see on page 59 that this method obviates the inverse grading effects anticipated by Mr. O'Gorman. We may conclude from that fact that the admitted advantages of this method over the so-called vacuum process (in which the papers are impregnated after they have been applied to the conductor) become even more marked when we are dealing with these very high pressures of 50 kilovolts and upwards. The author's "test sheath" seems to me to be of great value because, being separated from the protective sheath by relatively only a few layers of paper, it provides means of detecting damage to the lead sheath before sufficient water has entered to ruin the whole of the dielectric and so cause a breakdown. I should like particularly to congratulate the author on the division of his paper into two distinct parts for each type of cable discussed. He deals first with the physical and chemical properties of component parts of the cable, and secondly with the conditions external to the cable. This arrangement brings into well-deserved prominence the excellent work done by the author in regard to the design and use of vulcanized-bitumen cables. I feel that in the latter section this paper will rank as a classic; it should be of invaluable assistance to those who may hitherto have felt the need of some authoritative guide to the behaviour of bitumen cables, especially in tropical countries.

Mr. Taylor

Mr. W. S. Taylor: On page 64 the author says, "The advantages due to the chemical stability of pure manila paper and the durability arising therefrom are offset to some extent in practice by its hygroscopic properties." Then shortly afterwards he claims that the best method is to impregnate the paper before it is applied to the cable. The paragraph which I quoted seems to indicate that to impregnate first is not the best arrangement. Moisture is liable to be absorbed owing to variable atmospheric conditions, and unless very great care is taken to keep the moisture away from the paper before it gets through the lead-press I think there will be trouble. However, there are other considerations which come into play, and one must not make too much of that point. I want particularly to refer to rubber-insulated cables. The author makes a special point of the necessity of a good coating of tin. Some years ago I examined this question and I came to the conclusion that a good coating of tin was essential if a cable were to have a long life. Unfortunately, other people do not seem to have paid the same attention to this point, and one generally hears that the tin is used to protect the copper against the sulphur in the rubber. Really the tin is essential in order to protect the rubber against the copper, and this is emphasized by the author in his paper. To my mind it raises the question whether in England we are working on the right methods in connection with our rubber cables, our practice being quite different from the Continental and American practice. For instance, in America they do not use pure rubber next to the conductor, and still find that in most cases there is very little sign of corrosion after years of use. To my knowledge some cables made up with the vulcanized rubber in contact with the tinned copper have stood 12 years' working, and there is not even the slightest sign of corrosion. That seems to point to some defect in our methods. One American manufacturer said to me when discussing the point, "What is wanted is something to withstand the pressure. If a rubber compound can be made which will withstand the working pressure and ordinary wear and tear there is no need to put on that expensive gum" (meaning of course the pure rubber). Mr. Richards raised a very important point when he suggested that the user should inform the manufacturer of the conditions with which the cables had to contend, and then take the manufacturer's advice. If that were done many of the troubles with cables would not occur.

Mr. Tay[illegible]

Mr. Lepine.

Mr. L. J. Lepine: In regard to the 100,000-volt cable mentioned by one or two speakers, which Dr. Klingenberg* proposed to use in his suggested scheme for London, there seems to be some misunderstanding as to the voltage for which the cables would be designed. In reality they would be designed for 60,000 volts only. I have worked with Dr. Klingenberg for the last two years, and therefore I was able to go very closely into the question of these cables. The idea was to use single-core cables only, and to earth the neutral points, thereby having a potential difference of 60,000 volts only between any one cable and earth. To show that the German manufacturers are not at all sure of their ground in regard to this question of e.h.t. cable, I would cite an instance where a 100 sq. mm. section copper cable was called for. A German firm tendered for a 500 sq. mm. aluminium cable and a 120 sq. mm. copper cable; nothing smaller could be offered. The larger sections only were recommended, with the object of reducing the stress. The cable of 120 sq. mm. was ordered, and when it was delivered it was found that the section was only 100 sq. mm. It may be interesting to members to know that owing to the probable scarcity of copper the German Government has prohibited the export of any cable larger than 35 sq. mm. section during the war. This ought to improve British cable makers' chances abroad.

Mr. Fernie.

Mr. F. Fernie (*communicated*): On page 74 the author quotes a suggestion of mine as to the ultimate origin of

* *Journal I.E.E.*, vol. 52, p. 136, 1914.

[illegible] cable failures. The first is "osmotic influences." Assuming that he means electric endosmose, this can only [illegible] the insulation, as electric osmosis is purely a current effect. [illegible] current in the sound cable. The author's other suggestions are "incipient flaws, damage, or general weakness." If the first or third of these is true it reflects on the cable makers, [illegible] regard to "damage," why should not the positive cables suffer equally with the negative? I want also to take [illegible] the only field it has is an entirely artificial one created by cable makers' agents, who have for years recommended [illegible] confessing that he has only recently come to understand— [illegible] many causes of its failure. There is one other point on [illegible] for e.h.t. cables. The cables that the author has tested compare unfavourably with most of those which I have tested. I have never found that a bending test of "ordinary severity" reduces the breakdown voltage to [illegible] towards the opposite result.

[illegible] over dielectric to radius over conductor have been very clearly propounded by Dr. Russell (*loc. cit.*). Owing to the enormous difficulties—first, of producing an isotropic dielectric, and, secondly, of sufficiently controlling the test [illegible] by partially breaking down the dielectric to a radius at [illegible]

[illegible] tions was well known in the early days of electric [illegible] for instance, in the bare [illegible] occurred on the St. Pancras [illegible] into contact with the metallic sodium formed on the negative insulators by electrolytic action. In ordinary systems of buried cables the alkaline metals are not often found, [illegible] consist of hydrates, carbonates, and other salts of the alkaline metals. In the case which I illustrated on the screen (not referred to in the paper), the part which I indicated as [illegible] salts had been first driven by [illegible] of vulcanized bitumen, and after acting [illegible] by subsequent drying up had been left [illegible]

[illegible] lated cables for long lines at 100 kilovolts, I have [illegible] explained my general [illegible]

Mr. Beaver. would be a serious one on long lines, and forms one of those commercial items in very high voltage schemes which will automatically settle itself eventually in the most economical way. The statement quoted by Mr. Welbourn from the paper, to the effect that the inter-sheath method is not commercially justifiable below 50 kilovolts, relates solely to the cable and not to a transmission scheme at that pressure.

I think there is an error in his figure for the apparent power required to charge a cable at 11 kilovolts, viz. 18·2 kw. per mile, as it is not proportional to the figures which he gives for higher pressures. I think it should be about 12·3 kw. per mile.

I am glad to have Mr. Welbourn's confirmation of my statements as to the permanence of paper-insulated cables under reasonable conditions of usage, and to have his support in connection with my warnings in the matter of abnormal working temperatures. It is not sufficiently appreciated with regard to deterioration of most dielectric materials that, within certain limits which will vary somewhat for each material, time and temperature are proportionately convertible terms. I do not agree that there is any inconsistency in mentioning a length of time for commercial tests on cables, and omitting it when referring to a specific value of dielectric strength of a material, because it is generally accepted that the latter is the value of the electric stress which a material is just capable of supporting indefinitely.

With reference to Mr. Welbourn's remarks on the efficacy of the Vernier joint in dealing with the trouble of pulling out of conductors at joints, my experience is that the resultant trouble from expansion and contraction effects usually appears in those parts where the best facilities for movement exist. As this is almost always in the vicinity of joints, and as the palliative is applied to the joints, one would obviously expect valuable assistance from the Vernier design. Fig. 10 in the paper will, however, perhaps serve as a reminder that we know comparatively little of the mechanical stresses and their possible ultimate effects in other parts of the cable, and that different results may be produced by almost insignificant variations in the conditions of construction and laying. With regard to Mr. Welbourn's preference for the lapped form of insulation in joints, I have already dealt with the subject briefly in reply to Mr. Sparks, and would only add that the continuous-current conditions to which he refers are less severe than those of an alternating current at an equal (R.M.S.) voltage.

I note that Mr. Welbourn's experience as to the rarity of cases of failure due to direct chemical corrosion of lead coverings, and the comparative immunity from electrolytic trouble under present-day conditions of installation and maintenance coincides with my own, as stated in the paper. A further point, sometimes overlooked in post-mortem examinations of faults, is that signs of electrolytic action are often resultant on conditions allowed to arise by the primary fault, *e.g.* mechanical damage, and that such appearances may effectively mask the original cause of the fault. In my reference to bonding, I assumed that earthing would be understood, especially as reference was made to Board of Trade rules.

In reply to the various points raised by Mr. Pearce, my remarks as to the average size of cable which would be found commercially economical for pressures in the neighbourhood of 20 kilovolts had reference to the more general case of distribution to a number of areas in various stages of development. I quite agree that for his particular case of transmitting a large amount of power from one generating station to a main distributing centre the conditions may fully justify the size of cable which he has adopted. There are two points of view to be considered in such a case: first, the limit of current density fixed by working temperature conditions, which is largely dependent on the method of laying and the number of cables grouped in close proximity to one another; and secondly, the broad aspect of the whole scheme, in which cable considerations are simply an item. In the case where a large system of distribution to a number of outpost points is carried out at a pressure of 20 or 30 kilovolts the commercial considerations will be different, and it may be uneconomical to use a smaller cable than, say, 0·1 sq. in. to commence with, and quite economical to duplicate it at a later stage of development.

Mr. Pearce's eminently practical views on what might appear at first sight to be weaknesses and complications attendant on the use of the inter-sheath type of cable are interesting. So far as the cable itself is concerned, the effect of bending on the thin lead inter-sheath is unlikely to cause trouble, judging from manufacturing experience. It is applied very closely over the first part of the dielectric, and the preceding and succeeding layers of paper are tightly lapped. When the cable is bent the movement of the inter-sheath is controlled by the adjacent papers which slide smoothly and uniformly over each other and return to their original position when the bend is taken out or reversed. The firm enclosure of the inter-sheath and the uniform movement of the paper on both sides of it appear to prevent the distortion to which Mr. Pearce referred.

The use of special tappings in transformers, etc., or alternatively the use of special apparatus such as compensators, for the purpose of anchoring the potential of the inter-sheaths will not necessarily constitute complications from the supply engineer's point of view. Without them or their equivalent, there would appear to be no practical solution of the problem of constructing insulated cables for very high pressures; and just as the general advance of electrical apparatus has entailed demands on the cable maker, for instance in the accurate balancing of split cores in connection with protective switchgear, so the manufacturer of transformers and other electrical apparatus will be called upon to co-operate with the cable maker in meeting the requirements of the transmission system. It is a matter of general experience that mutual demands of this kind are invariably met when the necessity becomes sufficiently pronounced.

I am glad to have Mr. Pearce's opinion that the margin between working and test pressures on cables need not be so great as that mentioned in the paper, because the cable user's demands usually control the situation, and in many cases cables have to be designed for test conditions rather than working conditions plus a reasonable margin of safety. With regard to Mr. Pearce's views on the time element in pressure testing, I should be only too glad if reasons of a practical nature—indicated briefly in the paper—would permit me to agree with him. It would lighten the burden of testing in a large works to a very

[illegible]

[illegible] grounds for concluding that I do not approve of the use [illegible]

[illegible] critical, and call for little in the way of reply.

[illegible] only applicable to armoured cables laid direct in the ground, and has more direct reference to provision against subsidences of the soil than to expansion and [illegible] ends of ferrules, but would possibly allow the surface of [illegible]

[illegible] to which no exception can be taken.

[illegible] maker enter into the question. Taking a broad view of the matter in the light of present-day knowledge, it is quite conceivable that if one had to design a rubber cable [illegible]

[illegible] that it would be advantageous to have an a[illegible]

With reference to Mr. Fernie's communication, I gather that he is of opinion that the saponification type of deterioration may (or even must) occur on any vulcanized-bitumen cable having an insulation resistance less than infinity. With every desire to leave his premises as undisturbed as possible, I am afraid I cannot agree that the current which leaks through a normal dielectric will pass to or from a wet braid at one or even a number of earthed or partially earthed points. The resistance of a wet braid, even if saturated with acidulated water, is too high for current (even from a fault passing several amperes) to be traceable on the braid a few feet away. Disregarding this fact, however, and taking up his suggestion as to the calculation of the number of coulombs which would flow through the normal dielectric in the course of two or three years, I am driven to the conclusion that Mr. Fernie could not have made the calculation himself, because the net electrolytic effect per annum per mile of cable would be the equivalent of that due to about one or two amperes flowing for one or two minutes. It is unnecessary therefore to pursue the argument further by considering other important factors connected with electrolytic effects, such as current density, or to point out that my reference to osmotic influences had clearly no connection with the cause of faults but was simply a component of the deterioration ensuing after faulty conditions are established.

With regard to the field of utility of vulcanized-bitumen cable, I need only point to mining work as an example showing not only a splendid record in the past, but a rapidly growing demand which shows no sign of falling off. Its successful use in other directions for many years past—in fact, since the early days of electric lighting—is a matter of common knowledge.

Mr. Fernie's experience in the matter of bending tests can hardly have been shared by others, because one cannot imagine consulting engineers specifying tests which show negative results. The statement as to the improvement of the breakdown voltage by bending tests clearly points to the desirability of embodying them in the manufacturing processes.

NEWCASTLE LOCAL SECTION: CHAIRMAN'S ADDRESS.

By P. V. Hunter, Member.

(Address delivered 16 *November,* 1914.)

It is an important duty of engineers to recast their ideas sufficiently frequently for new conditions and developments to be quickly co-ordinated with existing practice. In no branch of engineering is this more necessary than in electrical power supply, owing to the rapidity of its growth. In such circumstances the retention of certain standards of method and construction, solely because they have been serviceable in the past, may lead to unsatisfactory results.

The tendency of engineering development in the production and transmission of electrical energy is in the direction of working on a large scale. As this tendency is due to economies which can only be obtained in this way, and as it persists in spite of obstacles other than engineering, it is to be expected that the size of generating plant and the radius of transmission systems will continue to increase. In the construction and operation of such large generating stations and supply systems engineering problems necessarily arise which are not apparent in smaller systems, although the only obvious difference may be that of size. One of the most interesting phenomena, and one which becomes of greater practical importance proportionately with the size of the system, is the mechanical forces experienced by circuits carrying heavy currents.

It is generally known, although not appreciated as a matter of practical interest, that any conductor carrying current experiences mechanical stress, the magnitude of the stress being proportional to the square of the current. In the case of a single straight conductor in homogeneous magnetic surroundings, so situated as not to be appreciably influenced by magnetic fields other than its own, the effect of the stress is to compress the conductor in cross-section and extend it axially. This is known as the "Pinch" effect, and I believe it has been used to promote circulation of the molten charge in electrical furnaces.

If two conductors carrying current are brought parallel to each other they both experience mechanical stress and are either attracted or repelled according as the currents are flowing in similar or opposite directions. A single conductor arranged in the form of a ring and carrying current experiences a stress tending to increase its periphery, *i.e.* a stress similar to centrifugal force. If the conductor be formed into a helix the effect of current is both to expand the helix in diameter and to compress the turns towards each other in an axial direction.

As the magnitude of all such stresses is proportional to the square of the current, they may while quite inappreciable with normal currents be of serious moment in the event of an abnormal rush of current amounting to many times normal load. It is in my opinion very necessary to recognize and provide against the effect of such stresses throughout the electrical equipment of a modern power supply system, and no less necessary in the case of growing systems. There is no difficulty or material additional cost involved in completely guarding against these mechanical stresses. In fact, they can be said to be a danger to apparatus only when ignored.

The stresses were first experienced as a matter of practical importance in the end windings of turbo-alternators. It was found that in the event of a short-circuit occurring either at the alternator terminals or in some circuit close to the power station, the rush of current in the alternator stator windings produced mechanical forces

[illegible] value of the short-circuit current is six or [illegible] mechanical forces can be readily dealt with. Any arrange- [illegible] forces are proportional to the square of the current.

An objection to the use of reactance coils or transformers [illegible] generator windings is that none of them can [illegible] for incorporating substantial additional reactance in the [illegible]

[illegible] number of conductors arranged one per slot, the self- [illegible]

On the whole it appears [illegible]

[illegible] current are by no means [illegible] mechanical stresses involved, and there is no [illegible] circuit current [illegible] with that calculated from [illegible] what extreme case, the total impedance voltage [illegible] possible, the difference between an impedance voltage of [illegible]

cal bracing necessary to withstand the severe stresses incurred under short-circuit conditions in the latter case.

A transformer having a full-load impedance of $2\frac{1}{2}$ per cent, and giving a voltage variation from no load to full load at ordinary power factors of approximately 2 per cent, is satisfactory from all points of view. Its voltage variation is sufficiently good for all ordinary purposes, and the stresses on short-circuit can be properly guarded against by bracing the coils, and without materially increased cost.

There is one precaution which should be remembered in connection with calculations of the short-circuit current. This current is usually deduced from a test in which the secondary of the transformer is short-circuited and sufficient voltage applied to the primary to circulate full-load current. The value of the voltage so obtained divided into the normal primary voltage will give the number of times full-load current which should be passed by the transformer under short-circuit conditions with full primary voltage maintained. This assumption is, however, only true if the leakage flux traverses a path which is air or its equivalent. If, for instance, a certain amount of iron is inserted in the leakage path in order to give higher reactance at full load, the value of the short-circuit current at full voltage deduced from the above method will be substantially too low. The method of inserting iron in the leakage paths is sometimes adopted in the case of transformers where a very bad regulation is desired.

It has also been found from experience that although a transformer may be so constructed and braced that when first installed it is fully capable of withstanding a short-circuit, it may not be in this condition after it has been in service for a few months. This particularly applies to oil-cooled transformers, where apparently there is some slight shrinkage of the insulation due to the action of hot oil. When this occurs the coils settle down, assisted no doubt by the vibration, which occurs in some degree with all transformers when in service. The settlement leaves the coils free to move, with destructive results in the event of a heavy short-circuit. It is therefore a wise precaution to examine each transformer after it has been in commission for a few months and to tighten all anchoring bolts. In some cases manufacturers provide strong springs which compensate for shrinkage of the coil. There is little doubt that this provision is of benefit, but it does not in my opinion do away with the desirability of examining the transformer and tightening everything up.

It is, I believe, a fact that the majority of transformers manufactured to-day have inadequate provision against the mechanical stresses of short-circuit. That more trouble is not experienced is no doubt almost entirely due to the fact that the generating plant is not able to maintain full primary pressure on short-circuit. This protection will disappear with the growth of the generating system.

In the case of the majority of the power-supply systems in this country it would be idle to suggest that their present development represents anything approaching their ultimate size, and there is very little doubt that transformers which are safe to-day on account of the inability of the generating plant to pass sufficient current to damage them will not be in this position later. Those who are at all dubious about the reality and magnitude of these stresses should read a paper by Steinmetz * which was published in the *Transactions of the American Institute of Electrical Engineers*.

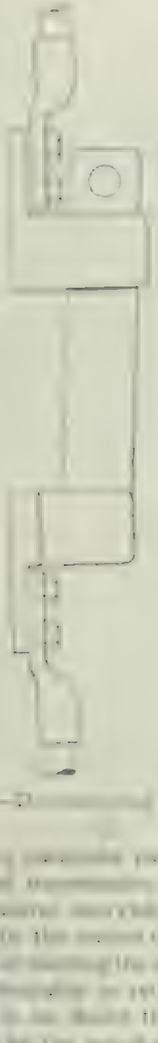
The above remarks are directed towards the ordinary power transformer. There is, however, little doubt that many current transformer failures if properly traced to their source are due to mechanical movement of the primary coils under a heavy rush of current. The current transformer is in the unfortunate position of not being able effectively to limit the value of the current which can be passed through it. In this it differs from generators and power transformers which put a limit to the maximum values of the currents by their own impedance. A sound mechanical construction of current-transformer windings may therefore be regarded as necessary. In this connection the soundest arrangement is decidedly that in which the primary consists simply of a bar without turns. Such transformers, it is true, do not maintain their ratio if at all heavily loaded on the secondary side, but with the exercise of a little trouble and ingenuity it is generally possible to use them almost exclusively on large switchboards. Their reliability from all points of view is so superior to that of any other type that they should undoubtedly be used wherever possible.

One curious effect of the mechanical stresses accompanying the flow of current is the tendency of knife-type disconnecting switches to open automatically under a heavy rush of current. The effect is similar to that which tends to increase the perimeter of a conductor forming a closed loop, and does not exist if the conductors above and below the switch are in line with it. It is, however, remarkable how small a deviation from a straight line is required to give this action. Fig. 1 shows a disconnecting switch which under a severe short-circuit opened automatically. If it had not been actually experienced I think one would doubt the probability of sufficient force being produced, with the arrangement shown, to open the switch, as this requires a pull of several pounds. This disconnecting switch, more than anything I have seen, brings clearly to one's mind the importance of attention to these mechanical stresses throughout the electrical equipment of a modern large power-supply system.

Even in the case of straight copper connections there may be considerable stress under short-circuit conditions.

As an illustration I will take the case of a line of busbars spaced at 18 in. centres, each individual bar being supported at intervals of 3 ft. In the event of a short-circuit between two adjacent bars sufficient to produce a momentary current of 100,000 amperes, each busbar support would according to theoretical calculation experience a force at right angles to its axis of some 900 lb. Now 100,000 amperes is a large but by no means impossible current; it probably represents the maximum instantaneous short-circuit current of about 50,000 kw. of generating plant at 5,000 volts. The forces are peculiarly destructive, as they are of a pulsating nature. The severity of the stress is of course increased if the conductor is at all able to move in its fastenings so that it can deliver a blow to the supports. There is one incidental precaution which

* C. P. STEINMETZ. Mechanical forces in magnetic fields. *Transactions of the American Institute of Electrical Engineers*, vol. 30, p. 367, 1911.



make this a little clearer I show in Fig. 2 the variation in effective voltage drop of a feeder due to a 5 per cent

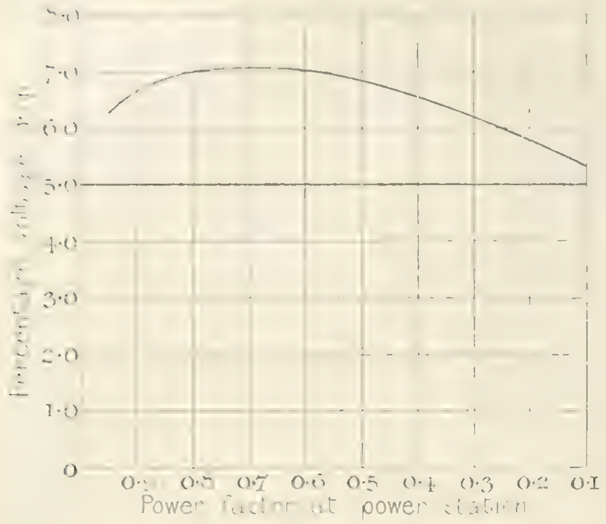


FIG. 2.

reactance, the resistance drop of the feeder at full load being assumed as 5 per cent.

It is obvious that on low power factors the permissible length of feeder must be reduced, as this is settled by the voltage drop. The simplest way out of the difficulty is to provide in addition to the reactance coil a voltage regulator on each feeder, which can be adjusted to maintain the voltage constant at the far end of the feeder under any normal condition of loading. In cases where it is necessary to use feeder reactance this appears to be the most satisfactory solution, particularly if the necessary reactance can be incorporated in the regulator. The transmission system can be more economically designed with a regulator on each feeder, as it is possible to make the feeders share the load more evenly than they would do normally. In any case those who are considering the adoption of feeder reactance are faced with the problem that, unless the power factor of the load is exceptionally good, either additional feeders or feeder regulators will be rendered necessary sooner or later.

On the whole it is desirable that the expense and difficulties introduced by the use of reactance should be avoided as far as possible, and for dealing with mechanical stresses it is first of all desirable to have the apparatus throughout so mechanically constructed as to offer the greatest resistance to damage. Having done this, the aid of reactance should be called in discreetly, using generator reactance as freely as necessary, feeder reactance only when really essential for safety, and reactance between busbar sections not at all, or only in exceptional circumstances on large networks.

INTERNATIONAL SYMBOLS.

REPORT ISSUED BY THE INTERNATIONAL ELECTROTECHNICAL COMMISSION.*

INTRODUCTORY REMARKS ON THE STANDARDIZATION OF SYMBOLS.

In so far as electrotechnics alone are concerned, it would seem possible to standardize symbols, and the following principles have served as the basis in the attainment of this object :—

The symbols must be clearly distinguishable one from another when writing with a pen on paper, with chalk on a blackboard, or with a typewriter. In the printed text, it is advisable to use a different type for the symbols from that of the text. It is desirable also that in ordinary handwriting one should not be obliged to add distinctive signs to symbols to specify the type to be employed. It should be possible to spell out the symbols when writing them on the blackboard. Finally, preference should be given to those symbols already in common use. From this it will be seen that it is impossible to make a distinction, in ordinary handwriting, between Roman letters and italics, and that small roundhand letters, being too difficult to differentiate from the above, cannot be used. It is generally agreed to abandon Gothic type, as requiring too long a time in writing. Finally, many of the Greek capitals are identical with Roman capitals. Taking the above points into account, there remain about one hundred symbols available in Roman, Script, and Greek type, of which several are already used for mathematical symbols and which are necessary for the purposes of the electrician. A list of symbols most frequently needed in electrotechnics is appended herewith. Taking into account certain symbols which are occasionally made use of, it is obvious that there will be none left for purely physical or mechanical quantities. Thus, in the same formula, electrotechnical symbols may occur in conjunction with other symbols used in mechanics and physics generally ; this is especially the case in equations containing mass, moment of inertia, speed, density, temperature, quantity of heat, etc. The International Electrotechnical Commission recommends, therefore, that in such cases, for physical and mechanical quantities, the symbol habitually used by physicists and mechanical engineers should be employed, if this symbol does not already exist in the formula as an electrotechnical symbol. If, on the contrary, it already exists in the formula, it is desirable that it be accompanied by a distinctive sign or that the notation be changed.

RULES FOR QUANTITIES.

(*a*) Instantaneous values of electrical quantities which vary with the time to be represented by small letters. In case of ambiguity, they may be followed by the subscript "t."

* Official copies of this Report, in pamphlet form, can be obtained from the Central Office of the International Electrotechnical Commission, 28 Victoria-street, Westminster, S.W.

[illegible] to be represented by capital letters.

TABLES OF SYMBOLS ADOPTED

I. QUANTITIES

Name of quantity	Symbol	[illegible]
1. Length	l	[illegible] L, M, T [illegible]
2. Mass	m	
3. Time	t	
4. Angle	α, β, γ	
5. Acceleration of gravity	g	
6. Work	A	W
7. Energy	W	P
8. Power	P	
9. Efficiency	η	
10. Number of revolutions per unit of time	n	
11. Temperature Centigrade	t	θ
12. Temperature absolute	T	Θ
13. Period	T	
14. $2\pi/T$	ω	
15. Frequency	f	ν
16. Phase displacement	φ	
17. Electromotive force	E	
18. Current	I	
19. Resistance	R	
20. Resistivity	ρ	
21. Conductance	G	
22. Quantity of electricity	Q	
23. Displacement, electrostatic	D	
24. Capacity	C	
25. Dielectric constant	ε	
26. Self-inductance	L	[illegible]
27. Mutual inductance	M	[illegible]
28. Reactance	X	[illegible]
29. Impedance	Z	[illegible]
30. Reluctance	S	[illegible]
31. Magnetic flux	Φ	[illegible]
32. Flux-density, magnetic	B	[illegible]
33. Magnetic field	H	[illegible]
34. Intensity of magnetization	J	[illegible]
35. Permeability	μ	
36. Susceptibility	κ	

[illegible footnotes]

(b) Maximum values of periodic electrical and magnetic quantities to be represented by capital letters followed by the subscript "m."

[illegible]

II. Units: Names and Symbols of Units

[illegible] after numerical values —

Name of Unit	Symbol
1. Ampere	A
2. Volt	V
3. Ohm	
4. Coulomb	C
5. Joule	J
6. Watt	W
7. Farad	F
8. Henry	H
9. Volt-coulomb	VC
10. Watt-hour	Wh
11. Volt-ampere	VA
12. Ampere-hour	Ah
13. Milliampere	mA
14. Kilowatt	kW
15. Kilovolt-ampere	kVA
16. Kilowatt-hour	kWh

m [illegible] μ [illegible]

k [illegible] M [illegible]

[illegible]

III. Mathematical Symbols and Signs

Name	Symbol	[illegible]
Total difference	d	d
Partial difference	∂	
Base of Napierian logarithms	e	[illegible]
Imaginary $\sqrt{-1}$	i	[illegible]
Ratio of circumference to diameter	π	
Summation	Σ	
Summation integral	$\int$	

1. [illegible]

2. The comma and the full-stop shall be [illegible] for [illegible] the [illegible]

stituting a whole number shall be indicated by a space and not by a full-stop or a comma (1 000 000).

3. For the multiplication of numbers and geometric quantities, indicated by two letters, it is recommended to use the sign $\times$, and the full-stop only when there is no possible ambiguity.

4. To indicate division in a formula, it is recommended that the horizontal bar or the colon be employed. Nevertheless the oblique line may be used when there is no possibility of ambiguity; when necessary ordinary brackets ( ), square brackets [ ], and braces { } may be employed to obtain clearness.

IV. Abbreviations for Weights and Measures.

Length :—m ; km ; dm ; cm ; mm ; $\mu = 0{\cdot}001$ mm.
Surface :—a ; ha ; m^2 ; km^2 ; dm^2 ; cm^2 ; mm^2.
Volume :—l ; hl ; dl ; cl ; ml ; m^3 ; km^3 ; dm^3 ; cm^3 ; mm^3.
Mass :—g ; t ; kg ; dg ; cg ; mg.

V. Name for Electrical Unit.

The International Electrotechnical Commission will recommend to the International Congress of the Applications of Electricity, to be held in San Francisco in 1915, the adoption of the name "Siemens" for the unit of conductance.

PROCEEDINGS OF THE INSTITUTION.

ORDINARY MEETING OF 12 NOVEMBER, 1914.

Proceedings of the 570th Ordinary Meeting of the Institution of Electrical Engineers, held on Thursday, 12 November, 1914—Sir John Snell, President, in the chair.

The minutes of the Ordinary Meeting held on 29 October, 1914, were taken as read, and confirmed.

The list of candidates for election and transfer approved by the Council for ballot was taken as read, and was ordered to be suspended in the Hall.

The President : I have to announce that in view of the large number of copies which have been sold of the Model General Conditions for Contracts the price has now been reduced to 6d. per copy, or 7d. post free.

A paper by Mr. C. J. Beaver, Member, entitled "Cables" (see page 57), was read and discussed, and the meeting adjourned at 9.52 p.m.

ORDINARY MEETING OF 26 NOVEMBER, 1914.

Proceedings of the 571st Ordinary Meeting of the Institution of Electrical Engineers, held on Thursday, 26 November, 1914—Sir John Snell, President, in the chair.

The minutes of the Ordinary Meeting held on 12 November, 1914, were taken as read, and confirmed.

Messrs. T. Stevens and W. A. A. Burgess were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the result of the ballot was declared as follows :—

Elections.

Member.

McKinstry, Archibald.

Associate Members.

Anderson, Arthur Augustus.
Binyon, Basil, Lieut. R.N.
De Renzy, William.
Lang, William Holland.

Graduates.

Carey, Theophilus Mattingly.
Dale, Tom Jesse.
Harrison, William Charles.
Marr, Albert William.
Norman, Harry.
Rickwood, Henry Asher.
Whaley, Ralph Stanley.

Students.

Abbott, Geoffrey Joseph.

Students—continued.

Dawnay, Cuthbert.
Gilbert, Herbert Williams.
Hyde, Cecil Lewis Garmston.
Khan, Lutfe Ali.
Partridge, Charles Frederick.
Sahgal, Sukhbashi Ram.
Skinner, Harold Edward.
Stubbings, Charles Henry.
Tosta, Joaquim Teixeira.

Transfers.

Associate Member to Member.

Hay, John Angus.
Lonsdale, William Stanley.
Matthews, John Charles M.
Westwood, Ernest Herbert W.

Graduate to Associate Member.

Price, Howard.

Student to Associate Member.

Carey-Thomas, Hubert.
Cranston, Walter Muir.
Goddard, Leslie Ward.
Goulden, Charles Herbert.
Martin, Leonard Cadoux.
Smith, William Balfour.

Student to Graduate.

Annacker, Joseph Peter.
Brazier, Clifford Claude H.
Dubash, Peshoton Sorabji G.
Hugo, Leon Pierre de Graaff.
Matthews, Frank Percy.
Munro, John William W.

The President announced that the Council had elected Professor Eric Gérard, Director of the Montefiore Electrotechnical Institute at Liège, an Honorary Member of the Institution.

A paper by Mr. W. M. Selvey, Member, entitled "Power Plant Testing" (see page 109) was read and discussed, and the meeting adjourned at 9.50 p.m.

THE JOURNAL OF

The Institution of Electrical Engineers

Vol. 53. 1 JANUARY, 1915. No. 239

POWER PLANT TESTING.

By W. M. SELVEY, Member.

[illegible]

[illegible] undoubtedly attached to it. The change that has come [illegible]

[illegible] nection with the capital cost of the plant installed. At that time the correct policy was to install cheap plant that was relatively inefficient, provided always the price of the plant was not cut down at the expense of reliability. This [illegible]

[illegible] efficiency of power plant, an item, which is now termed obsolescence, was omitted from the old balance sheet. Recasting the balance it is now seen that this item stands out prominently (or should) compared with the real interest and depreciation, which latter are essentially of a different nature. This item is large, not only when compared with generating-station costs, but also with distri- [illegible]

Though it is a matter open to discussion, it is the author's opinion that unless provision is definitely made for replacing obsolete plant out of revenue, no longer than eight to ten years should be allowed—if not on paper, at least in the mind of the buyer—for complete obsolescence of plant purchased at the present time and rated at less than 5,000 kw. in the case of turbo-alternators, or 30,000 lb. per [illegible]

[illegible] its point of application, so to speak, will have m[illegible] terminals.

[illegible] known as the bonus or penalty clause has become the [illegible]

A short illustration may bring home the meaning of this, though the figures must not be taken as exact.

[illegible] hours per annum. The n[illegible] variation of 1 per cent in this output, taken on a coal cost of 0·15d. per unit, is £375 per annum. Capitalized on the [illegible] two competing machines, if one [illegible] per cent [illegible] sumption.

[illegible]

justify very considerable care and expense in the testing of such a plant. The accuracy of the test should be worthy of the aims of the manufacturer.

There are several firms—not counting simple licensees—who are endeavouring to utilize every possible advance in efficiency in the design of their machines, but are compelled at the present time to quote prices that do not in any sense take into account the actual efficiency obtained, while on the score of reliability unfortunate occurrences are by no means confined to any one maker or any one type of machine.

The value of 1 per cent of the output must also be taken into account in the boiler house. Sufficient has, however, been said to indicate the atmosphere of modern advance in power plant at the present time, and the bearing of the question of accurate testing on the subject.

It is proposed to consider the various plant installed in a power station, noting their efficiencies and the methods available for establishing the latter, and taking them in the following order :—

(1) Boilers and economizers.
(2) Turbines and alternators.
(3) Condensers and air pumps.
(4) Auxiliaries : Cooling towers, fans, pumps, etc.

Boilers and Economizers.

The efficiency of boilers has received much attention of late years, owing to the energetic advertisements of makers of CO_2 apparatus. The use of the term CO_2, meaning thereby the percentage of carbon dioxide in the flue gases, has become very common. It is a convenient way of denoting the amount of excess air in these flue gases over and above that which can take any part in the combustion of the fuel.

In Figs. 1 to 3 the efficiency obtainable is expressed in terms of the CO_2 and the final temperature. Fig. 1 is for a Staffordshire slack coal, and Figs. 2 and 3 are for a Northumberland steam coal. The ideal percentage of CO_2 varies with the ratio of hydrogen to carbon in the coal, but in most English coals the variation is not more than will cause the ideal amount of CO_2 to vary from 18 per cent to 19 per cent.

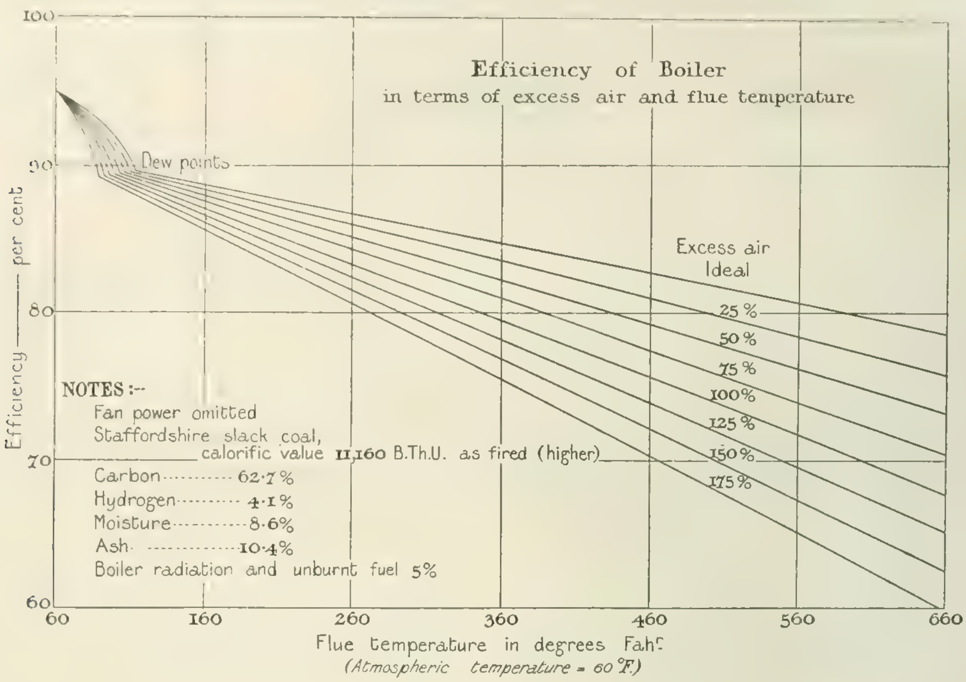


FIG. 1.

Since this is one of the principal measurements in boiler testing, the author may be pardoned for calling attention to a modified form of Orsat apparatus, shown in the lantern slide, which has been developed for readily analysing the sample taken. The variations from other

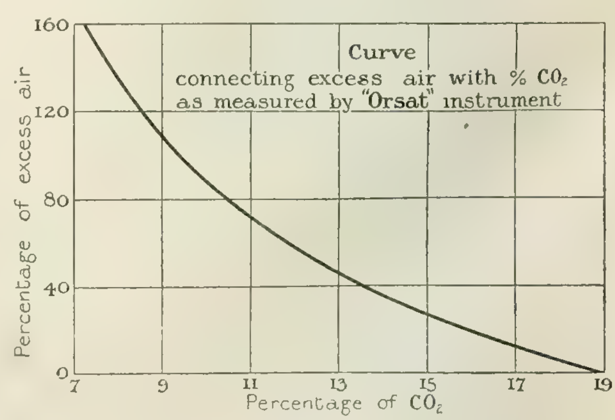


FIG. 1A.

[illegible] but they had to [illegible] and [illegible] at working.

The method of collecting the sample [illegible] thought, and the author thinks that the arrangement shown in Fig. [illegible] will be found to give reliable results. [illegible] through a sampling [illegible] a small [illegible] for this purpose.

[illegible]

[illegible]

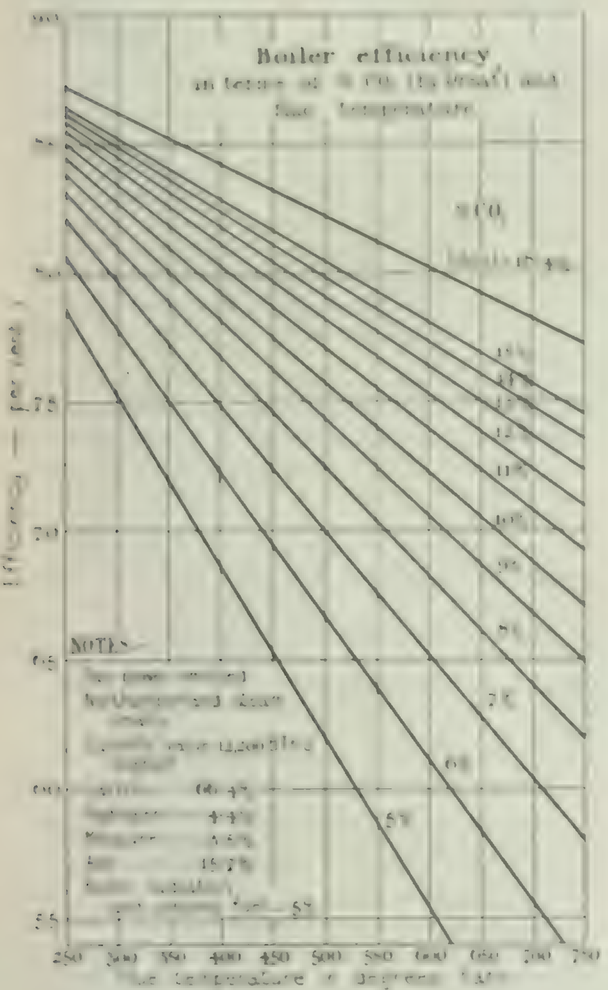


Fig. 2.

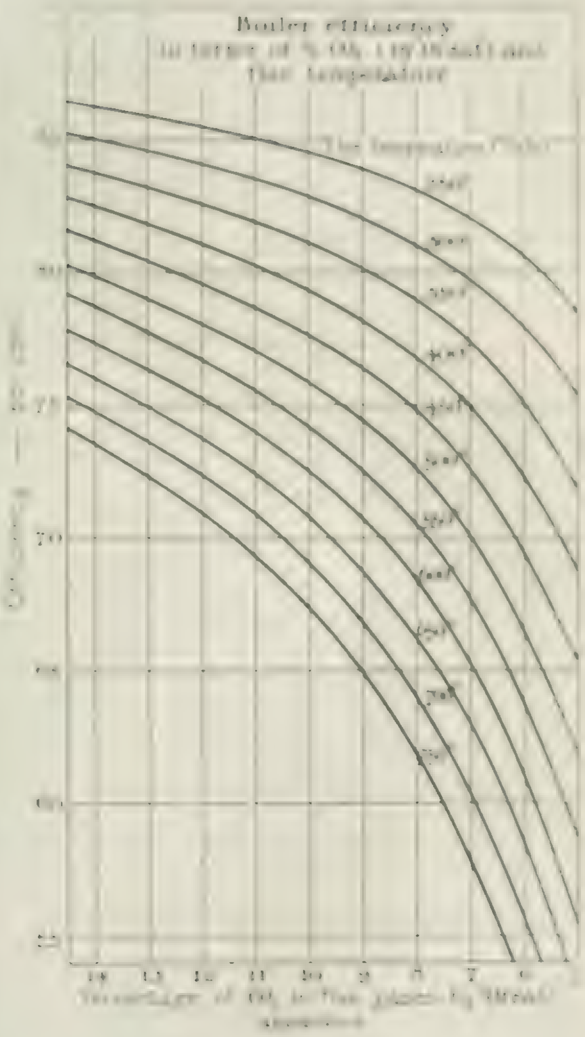


Fig. 3.

[illegible]

The diagrams indicate that the other main measurement which determines the efficiency of the boiler is that of the final temperature.

The author has for some years used platinum–platinum-rhodium couples for the higher temperatures and copper–Constantin couples supplied by the Cambridge Scientific Instrument Company and checked at the National Physical Laboratory. The results have been entirely satisfactory, particularly when the wires are insulated with the "Vitreosil" product of the Thermal Syndicate.

[illegible]

[illegible] construction.

[illegible] that does not suffer either in efficiency or [illegible]

coal is either too bad or too good. If the boiler is designed for a good coal, and by this should be understood a coal giving anything above 12,800 B.Th.U. as fired, or below 8 per cent of ash, it cannot maintain combustion at all with some coals. If, on the other hand, the boiler is designed for a bad coal (11,000 B.Th.U., or less as fired, or above 16 per cent of ash) the temperatures attained when working at its best, and with good coal, are such that no brickwork will stand. The best working can only be got by keeping the quality as uniform as possible, and this is the real difficulty.

The author has while testing a sample 10-ton truck-load* of coal on a 100 sq. ft. grate, found the amount of CO_2 to drop from 14 per cent to 8 per cent, and the

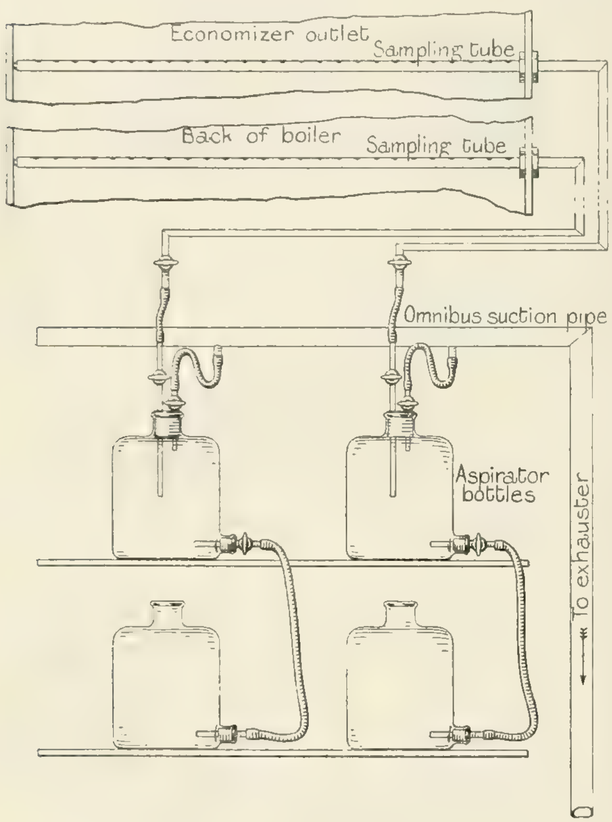


Fig. 4.—Apparatus for Sampling Flue Gases.

evaporation from 30,000 lb. to 18,000 lb. per hour, and he expects that others have had a similar experience.

With a stoker and furnace specially designed for coal with a very high proportion of duff, with which only 8 per cent of CO_2 could be got with great effort, a run of good coal has softened the arch and made the walls "run in" in less than an hour.

It is comparatively easy to produce an amount of CO_2 ranging from 12 per cent to 14 per cent on a chain grate with a long arch when the duff is not above 30 to 40 per cent; but when this rises above 60 per cent it has an extraordinary blanketing action on the fire, and it is difficult to keep the amount of CO_2 up to 8 or 9 per cent, even under test conditions. To sum up, an average of 10 per cent would be exceedingly good working. This refers to the

* A suggested standard amount of coal for a trial.

gases at the boiler exit. The amount of CO_2 at the economizer exit is often 2 per cent lower, and this difference is one that will repay close attention.

If anything can be done, it is well to separate as far as possible the known bad coals, and to burn them on a specially arranged furnace adapted for such types of fuel. A scheme something like this has been adopted at Birmingham for the riddlings, and was referred to by Mr. R. U. Bailey at the discussion on Mr. Fedden's paper* before the Incorporated Municipal Electrical Association this year. Members can also apply their knowledge of their local conditions to the curves in Figs. 1 to 3.

The size of the economizer has a large effect on the final temperature. The temperatures on full load should be taken, say, 24 hours after sweeping, and should be used as a standard. If at any subsequent time the boiler exit temperature is found to be 150° F. higher, or the economizer outlet to be 100° F. higher, the boiler needs cleaning.

Values of 600° F. for the former and 350° F. for the latter may be considered satisfactory. The lowest temperatures that the author has met with in this connection are about 450° F. for the boiler outlet, and 240° F. for the economizer outlet. He is informed that temperatures as low as 160° F. have actually been obtained, but this was probably with a co-operative economizer with only a few of the boilers working.

Remarks bearing on the arrangement of the economizer, the temperature of the feed water, and the fan power have already been published in the *Journal*† and need not be here repeated. A result therefore of, say, 10 per cent CO_2 and 300° F. final temperature, both measured at the economizer outlet, may be considered a good test result. The author thinks that many engineers are unaware of the average amount of CO_2 in their boiler houses, and he would be surprised to find if when taken over the 24 hours it was in many cases anything like as high as 6 per cent. It is in this direction that close supervision in the boiler house will pay, not during morning and evening peaks when conditions are at their best, but at the times of light load and during the night.

From the operation point of view of testing, this completes the case for efficiency, but from the point of view of the contractor's test and commercial coal testing it is advisable that one boiler of a type should be set aside for testing work, and fitted up with measuring instruments.

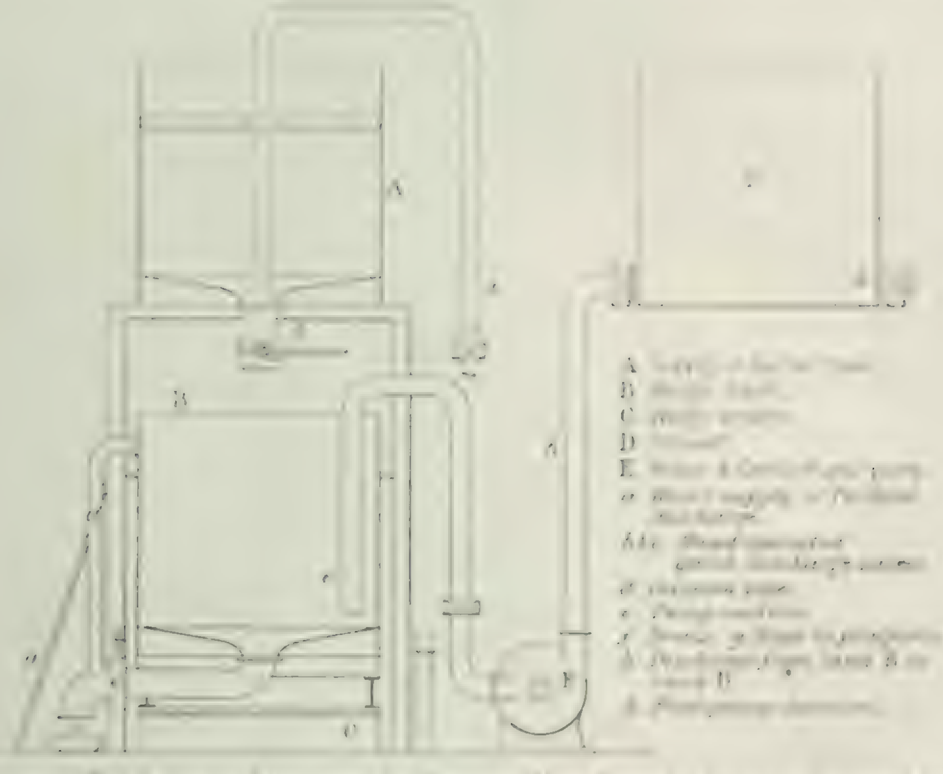
A sample truck or trucks of coal can then be run through the grates, and the actual evaporation measured. The author does not wish here to go into the question of hand and automatic sampling, except to mention in passing that with accepted methods of hand sampling discrepancies of as much as 7 per cent have been obtained in his own experience, and also in that of co-workers in the United States, who as is usual have gone into the question on an extensive scale.

Even if the sample is correctly taken, the author's feeling in the matter would always lead him to have the sample analysed by a chemist of special experience, and he is greatly indebted to a well-known chemist for making many of his attempts at accuracy in this direction at all possible.

* S. E. Fedden. Design and operation of modern boiler-house plant.

† *Journal I.E.E.*, vol. 52, p. 481, 1914.

[illegible]



[illegible]

[illegible] grate.

[illegible]

[illegible] there is none that has been developed to so great an accuracy.

As regards the steam end of the plant, measurements of the temperature of the steam have been greatly improved, both by the use of the Whipple indicator and by the [illegible]

[illegible] the result of stilling the ordinary steam velocities involved in this question is calculated, it will be seen that this point is of little importance.

[illegible] importance, but in certain cases where defect in [illegible] importance.

[illegible]

and mainly concerns the condenser. The vacuum should be measured at the exhaust flange of the turbine—a difficult but most important measurement.

The author has never seen a really satisfactory mercury column suitable for peripatetic testing, and has always manufactured his own. He has also found it necessary to have a special aneroid barometer made for this work. After using a mercury barometer for some years he was thankful to keep it hung up as a standard and to use an aneroid barometer, which has been brought to a very high state of perfection. A good stop-watch is so excellent a piece of apparatus as to call for praise rather than comment.

The measurement of the condensed water offers little difficulty, thanks to the manufacturers of weigh-bridges. The accuracy of these can be easily made better than one in a thousand (0·1 per cent),* which is the ideal that the author thinks ought to be aimed at in each individual measurement in turbine testing if the final figure is to have anything like an absolute accuracy of 1 per cent.

The tank and the electrical meter measurements should be absolutely correlated by bell, light, and telephone signals, without the intervention of the time element at all. It should be purely a measurement of matter against energy.

Electrical Meters for Generator Outputs.

(*a*) *Continuous current.*—The circumstances of continuous-current measurements unfortunately render it necessary in most cases to depart from the ideal laid down in the previous paragraph, as, owing to the temperature coefficient of almost all large continuous-current watt-hour meters, it is a better policy to use precision voltmeters and ammeters except with extremely variable loads. Even then, there are many precautions to be taken. Stray fields, often severe, affect not only watt-hour meters, but even reasonably-shielded indicating instruments. For this reason it is well to re-check any instrument against its test-room calibration, by means of a potentiometer and standard cell, when the instrument is actually *in situ*. If this is inconvenient, long leads should be provided at the time of the test-room calibration so that the position of the instruments may be chosen with considerable care.

Further, the main shunt should be designed and fixed with more insight than is usual with shunts for ordinary switchboard instruments. Errors due to change of resistance, unequal heating, and thermo-electric effects, are quite appreciable if the temperature approaches 85° F. It is well to arrange to include thermometers inside test instruments, the bulb being placed close to the actuating part. Without excessive pressure-drop in the shunt the temperature coefficient of these instruments is likely to be more than 0·03 per cent per 1° F.

(*b*) *Three-phase current.*—The author has had experience with the meters of only two of the principal electrical firms of this country, in conjunction with Mr. Fawssett of the Newcastle-upon-Tyne Electric Supply Company, to whom he is indebted for much of his knowledge of continuous- and alternating-current meters and whose efforts have resulted in a progressingly increasing accuracy of these meters under test conditions. The National Physical Laboratory, whose work in this direction is beyond praise, have tried to get the method of using these meters standardized, and it is the author's opinion that the only satisfactory method is to take in duplicate the whole set of pressure transformers, current transformers, leads, and meters, to the National Physical Laboratory—or, say, the Manchester University—before a test, have them thoroughly checked, and then tally every lead on breaking circuit. All the gear should then be brought by hand to the user. The meters should be mounted in a remote control room, quite cool and free from vibration, the length and section of the leads having been prearranged to allow for this.

By following this method results have been obtained that are quite consistent with the ideal 0·1 per cent in regard to the comparative behaviour of two complete and independent sets of meters and transformers.

With some forms of switchgear it is only possible to take the maker's word for the ratio of the transformers, if the testing is to be done "on the system," which it always should be if possible. The meters alone are then checked. This may give fairly satisfactory results in the hands of an expert if the meters are run on unity power factor. Efficiency tests should always be run on unity power factor unless there are serious reasons for the contrary.

It is necessary in this paper to omit many questions which could here be raised, such as correct phasing in,* the use of instrument fuses on the high-tension side, earthing a common point of the pressure and current secondary windings, adjustment for power factor, and the regulation of voltage and load.

In summing up, the author would say that in turbine testing no measurement can under the best conditions yield happier results, or on the other hand more serious discrepancies. In a recent case within his own experience, a station engineer proposed to reject entirely a turbine plant on results obtained by using the mean reading of three meters which differed 7 per cent among themselves.

Condensers and Air Pumps.

It is almost impossible to arrive at any just appreciation of a condenser performance without knowing at the same time the air leakage with which the air pump is dealing and the rating of the pump. In this direction the Scanes gauge will be a great educating force.

Five years ago nearly everybody used Edwards air pumps, and but for the unavoidable cooling of the condensate and the upkeep of reciprocating machinery in no respect can the combination of a Parsons augmentor and an Edwards air pump be surpassed in reliability or capacity to-day, neither is there any other system so low in its power requirements. In spite of this they are seldom fitted to newer plants. This seems to the author to be a most striking example of reciprocating plant being superseded by rotary plant.

The ability of a steam jet to handle large volumes of gases is unequalled, and the author thinks that the ultimate

* In a particular instance the error of a new machine was less than 5 lb. in 35,000 lb.

* *See* E. Fawssett. A power company's testing department. *Journal I.E.E.*, vol. 47, p. 752, 1911.

[illegible]

[illegible]

[illegible] same vacuum [illegible]

[illegible] greatly. One eminent authority claims to have reduced it [illegible] of steam. To include provision for occasional leaks, the [illegible] tained by the air pump when dealing with this amount of air, but disconnected from the condenser, should [illegible] water that it is using. The author would like to hear [illegible]

The individual rating of the air pump being thus settled, [illegible] depends almost entirely on the steam distribution. The author's feeling is that the buyer should specify the surface that he requires, especially if he is at all troubled with dirty condensing water. In this case it is well to arrange for [illegible] The author thinks that expenditure in that direction is money well spent.

With the introduction of modern air pumps, figures such as 7–10 lb. per sq. ft. per hour are being offered even where high vacua are required. The author suggests, [illegible] pump already described, should be expected to have, three days after brushing the tubes, a value of "K" not less than 450, and he would invite discussion on this point. The onus of making the plant airtight would thus be left on the contractor.

[illegible] per square foot of surface per hour per degree (Fahr.) mean difference between the temperature inside and [illegible] to be uniform and measured at the inlet, and the water temperature to be the mean of the inlet and outlet tem-

[illegible]

COOLING TOWERS.

[illegible]

[illegible] the consumption of the turbine plant, and bearing in mind the value of 1 per cent as shown in the intro- [illegible] and cut down the height of the chimney, since cooling towers are so cheap.

[illegible] care is necessary [illegible] free stream of air passing over them. On a ce[illegible] cooling-tower test the close proximity of the observer to the dry-bulb thermometer was found by the author [illegible]

[illegible] of the tower, and in the shade if [illegible] should always keep to leeward when reading, and the [illegible] change of wind or bright sunshine can in any way affect the correctness of the readings.

[illegible] put in the inlet to the condenser, and another in the outlet as far away from the condenser as may be convenient while still in the engine room, and if a [illegible]

[illegible] tower as to obtain the guaranteed temperature at the

inlet of the circulating pump or condenser,* and outside this he should be allowed a free hand.

It is difficult to measure such large quantities of water as are cooled in towers, say, up to 250,000 gallons per hour. It can of course be done by a Venturi meter, or weir. Alternatively, it is much better done by the thermal method, in which the amount of water is calculated from the measured condensate, its known loss of heat per lb. in the condenser, and the rise of temperature of the circulating water.

Contrary to what may be imagined, this test properly run is of considerable accuracy. The principle is the well-known one of adding a known quantity to the unknown quantity to produce a mixture of which the properties are measurable. To mention parallel applications, the Thomas gas meter adds a known number of watts to a stream of gas and measures the rise of temperature.

In testing large water turbines, a steady stream of concentrated salt solution is added to the incoming water, and the tail-race water is analysed for salt.

The same principle is commonly used for finding condenser leakage where the circulating water is salt, and removes the necessity on a turbine test for having the condenser absolutely watertight.

Centrifugal Pumps.

It is seldom that a test of a circulating pump is required in power-station work, other than making certain that the pump provides sufficient circulating water. On site, if no Venturi meter is fitted, the test is best made by the thermal method. It is more convenient, however, to carry out the test at the maker's works where calibrated nozzles, Pitôt tubes, or V-notches are available. It seems to be a common mistake with these pumps to use too small a motor and too large an impeller. Probably the pump maker intends the impeller to be turned down in any case. It is, however, rather unfair to the motor, and an early test of the amount of power taken is always advisable.

A point arises in connection with these pumps when tested on a rigid specification for efficiency. Owing to the speeding up of pumps for direct coupling to motors, water velocities have risen from 6 ft. to 20 ft. per second. The water leaving the pump has therefore appreciable kinetic energy, part of which can be converted into head by an expanding nozzle. The specification should say whether the efficiency is to include this regained energy.

Fans.

Fans are in a very fortunate position at present as a very high efficiency is never expected from them, and they are thoroughly reliable provided the main bearings do not lose oil by a suction effect. It is seldom that fans have an efficiency much above 65 per cent, and the means of testing them have not been highly developed for ordinary commercial use.

In the author's opinion the best way to test them is to discharge the air through a set of home-made wooden nozzles of suitable size which can be fitted in turn on the outlet of the fan. The calculation of these is very simple; the shape can be that which has been laid down for maximum water discharge, the discharge coefficient for which is very nearly unity.

He thinks, however, that the efficiency of fans will receive close attention in the future. In order to make the boiler as flexible as the turbine, condenser, and alternator, much greater fan power will be used, and the draught used will probably rise to 6 in. water gauge.

He also believes that a higher-efficiency fan will be introduced, together with a variable-speed motor for economizing the draught when the latter is not required. Attention will then be much more focussed on this auxiliary, which will absorb 200 to 250 kw. for two boiler units of the size already in use in the United States. No doubt by that time a method of testing will have been standardized.

General Remarks.

The organization of the personnel for accurate testing is a matter for concern. The larger a permanent staff can be kept for this work the better, and in the author's opinion in no case is it advisable to undertake any permanent testing work unless there are at least three engineers, or two engineers and a chemist, in constant collaboration with each other. The idea that anybody can carry out a test, or that any people are good enough for taking readings, must be abandoned, although on the whole the author's experience is that a practical man, such as a first-class engine-driver, with a little training and encouragement is generally to be preferred to many graduates from our modern colleges. The author mentions this with some regret, as he is an enthusiastic educationist. For testing assistance what is mainly wanted is sincerity, and the man who knows a little and uses that knowledge is greatly to be preferred to the man who knows a lot and doesn't use it.

In arranging a test it is advisable to have full instructions typed out and handed to every person engaged in a trial; and even then it is necessary to make certain that these instructions are read. The author has almost entirely abandoned sound signals in favour of lights, although sometimes a powerful hooter is a welcome assistant in a big station.

It is his practice to take all readings in triplicate, and in case of very important trials to have one power-station man and one contractor's man to take each particular set of readings in conjunction, so that any disagreement may be dealt with at the time and on the spot. He must say, however, that with nearly all the contractors with whom he has had to deal, it has been a pleasure to test their plant, many of them taking only a nominal part in the proceedings. This produces a very good impression on the customer.

There are rare cases where a plant has to be tested by measuring the water pumped into the boilers, and this calls for a special test on the boilers alone, generally known as a "still" test, in order to measure any leakage. It is a difficult test to carry out, as even with everything shut down the circulation rate of the water contained varies if the pressure rises or falls, and since a small fire has to be kept going to make up for radiation losses it is very difficult to avoid one or the other. By testing on a rising pressure it is easy to make the amount of water in the boilers appear to increase, but the author is satisfied that a batch of five boilers can be isolated and made absolutely

* 774 ft. head = 1° F.

[illegible] above suspicion.

[illegible]

[illegible] time of the year that the vacuum producible is superior to [illegible]

It is very important that the condenser should be tested [illegible] circulating water on, and then to open a connection between the water extraction pump and the condenser at the lowest possible point. Ample time must be given to the condenser to drain before assuming that any water running out is leakage. The method favoured by the author, however, is that when the brushing of the condenser tubes is finished the inside of the condenser should be filled up with fresh water on the steam side to as high [illegible] actually indicating the leaking glands or perforated tubes, and at the same time revealing any small air leaks that there might be in the casing. Very satisfactory results can be obtained by this latter method, and the author has seen the tube plates on a condenser filled in this way absolutely dry after being left over night.

[illegible] ing during the trial the chloride contents of both the circulating water and the condensate it is easy to calculate the leakage. It is not so simple, however, to do this with fresh circulating water, and electrical resistance methods [illegible]

From the personnel point of view it is unwise to carry on [illegible] nection between the fatigue of the observers and the [illegible]

[illegible] period.

[illegible]

[illegible] lime it is [illegible] the contractor the option of cleaning them, [illegible] deposit is in no way due to the turbine. It [illegible] the way the boilers are being run. The auth[illegible] to execute any [illegible]

[illegible]

In presenting these few remarks the author hopes that he has suggested grounds for the following points :—

[illegible] plant.

The equalizing of conditions under which these tests are run.

The value of the data gained from tests for routine operation.

[illegible]

APPENDIX I.

[illegible]

[illegible]

standard instruments at the National Physical Laboratory, Teddington.

No. [illegible], N.P.L. 13. Range [illegible] Reading	Correction	No. 68 N.P.L. 13. Range 500°–650° F. Reading.	Correction
At 32° F.	0·0	At 32° F.	—0·1
212°	0·0	212°	—0·1
305°	—1·0	520°	—1·5
400°	—1·0	570°	0·0
440°	—1·0	610°	0·0
550°	—1·0		

Note 1.—When the sign of the correction is +, the quantity is to be added to the observed scale reading, and when —, to be subtracted from it.

Note 2.—The corrections refer to the air scale, accepting 444·5° C. as the boiling-point of sulphur, and are applicable only when the instrument is immersed to the reading. If not totally immersed, the corrections depend to a considerable extent on the temperature of the emergent column.

Note 3.—This thermometer has been tested only at the above points as desired.

APPENDIX II.

Cooling Tower Guarantees.

Particulars	Steel Tower (A)	Wooden Tower (B)
Gallons of water cooled per hour ...		
Height of tower		
Area of base (water surface)		
Area of chimney		
Gallons cooled per square foot per hour		

Range of Cooling with Fixed Inlet Water Temperature of 95° F.

Atmospheric Temperature	Cooling by Steel Tower			Cooling by Wooden Tower		
	Humidity			Humidity		
	60 %	75 %	90 %	60 %	75 %	90 %
40						
55						
70						

The normal conditions are to be taken as 55° F. atmospheric temperature with 75 per cent humidity.

The 70° F. atmospheric temperature with 90 per cent humidity may be omitted.

NOTE.—If it is ever necessary to compare two makes of towers generally similar, the only satisfactory way is to supply them with a fixed quantity of warm water per square foot of base at a constant temperature, and to find to what lower temperature they cool it. This involves the adjustment of the load in order to keep the top temperature steady, and gives as a final result the rating of the tower in kilowatts for a given top temperature.

This is a most delicate test and brings out very clearly any difference. It is an almost direct comparison of the velocities of the air up the respective chimneys, since the quantity of the water and its mean temperature are practically unaltered. Differences in otherwise similar towers are then due to the degree of freedom from obstruction of the air passage by the distributing apparatus, and the completeness of the saturation of the air in the chimney. These two requirements are to some extent conflicting.

The author does not agree with the statement that the cooling is the same as long as the wet-bulb temperature is unaltered. The heat-carrying capacity of the air per cubic foot is almost constant, but the draught up the chimney gets less as the dry-bulb temperature rises.

The statement is, however, practically true when applied to forced-draught towers.

DISCUSSION BEFORE THE INSTITUTION, 26 NOVEMBER, 1914.

Mr. Chattock.

Mr. R. A. CHATTOCK: In my remarks I propose to deal more with the principle of power-plant testing than the author has done. I consider it is of the utmost importance from the buyer's point of view that the testing of the whole of the main plant in a power station should be carried out with great accuracy, and that the results obtained should be absolutely reliable. The carrying out of such tests requires trained observers, and such men are not always to be found in central stations. In large power stations no doubt suitable men can be found, but in the smaller stations, of which there are a very large number, it is generally difficult to find men who have had sufficient training for the purpose, so that it is usual to rely upon the contractor to provide the men to carry out the tests. It would of course be very much more satisfactory to employ an independent testing authority for this purpose where one is available, and one feels that even amongst experts it is necessary to obtain men who have had considerable experience in this class of work. I think also that even in a large power station such a mode of procedure is advisable, because when there is much testing to be done, the time of the engineers in charge of the station is taken up, and it withdraws them from their ordinary duties, thereby probably interfering with the running of the station to a considerable extent. There is one point that I want to emphasize strongly: it is practically useless to test a plant unless the conditions of testing and the guarantees as to the performance of the plant are clearly set out in the specification. In most specifications of plant there is very considerable diversity in this respect. Different men have different ideas. The requirements that the plant has to meet are stated in entirely different ways, so that contractors must experience great difficulty in carrying out the tests required to demonstrate what the plant can do. Unless, therefore,

[illegible] permanently in the power station. [illegible]

[illegible] in his paper. One naturally requires a cooling tower to [illegible] degrees. That is a very simple matter, but in practice the action of the tower depends upon the temperature and humidity of the atmosphere, the temperature of the inlet [illegible] to ask the contractor for the cooling tower to submit a [illegible] of his tower under widely varying conditions. All those points require practically as much knowledge and experience in the testing of the plant on the part of the engineer drafting the specification as on the part of the engineer [illegible] the conditions as regards all the [illegible] power station it would very much improve the [illegible] of the plant which central-station [illegible]

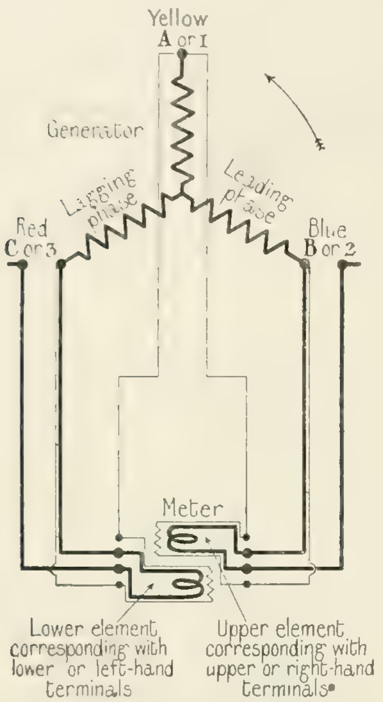
Mr. C. C. Paterson: [illegible] to that part of the paper which deals with the electrical instruments used for the tests which the author describes —a part of the subject with which he has not dealt with at great length. The author shows very clearly that an [illegible] a considerable difference in the cost of running the station. [illegible] this is now being recognized to be worth having from the financial point of view. That is all to the good, as more serious attention, such as the author has given to the subject, will eventually be paid to the real advantages of making tests to as high an accuracy as possible. [illegible]

[illegible] under those conditions the meters are accurate. For the [illegible] In the calibration of a meter for [illegible] power plant, say of the order of [illegible] volts, the power, it must be remembered, [illegible] many links in the long chain connecting these two with [illegible] chain. Mr. Rayner, Mr. [illegible] year [*] the apparatus which we have [illegible] ing out tests of this kind, and I will not therefore discuss it now. Apart from the questions of the constancy and of the [illegible] just referred to, which we think it is most [illegible] is, I consider, [illegible] not be assumed to be correct, and errors of several per [illegible]

* C. C. Paterson, E. H. Rayner and [illegible]

Mr. Paterson.

whatever. Better, I think, to refrain from the attempt to make accurate tests at all than obtain results of which the correctness has such a risky and uncertain foundation. It is also fallacious and undesirable in our opinion, as has sometimes been suggested, to try to test 3-phase meters on single-phase circuits. Unless 3-phase meters can be tested on 3-phase circuits, I consider it very much better to measure the power with two or three single-phase watt-hour meters instead of with a single 3-phase watt-hour meter. Another point which I wish to mention is that in the connecting up for test of the usual 2-element 3-phase watt-hour meter it makes a great deal of difference whether



Looking at front of meter

FIG. A.—Diagram showing the convention for connecting a 2-element 3-phase watt-hour meter to a 3-phase network, in order to ensure that each element has a definite relation to the direction of rotation of the system.

the two elements of the meter have the same relation to the direction of rotation of the system as they had when calibrated. A 3-phase system has a certain electrical direction of rotation—each phase lagging behind the one preceding it. Each of the two elements must, therefore, be confined to use either in one or other of the phases, and they must not be interchanged. I mentioned this point about three years ago* and pointed out that errors of 4 and 5 per cent sometimes occur owing to interchanging the two elements. Since then manufacturers in this country have at our suggestion agreed always to connect these meters in a certain way. Fig. A shows the arrangement that has been agreed upon, and ensures uniformity in this respect. In all modern British-made meters the lower element corresponds with the lower or left-hand set of terminals and is to be connected to the lagging phase of the system. The marking or colouring of the phases is also defined in the diagram and has become standard with meter manufacturers. Mr. Paterson.

Mr. R. HAMMOND: I am particularly interested in this paper because for very many years I have felt the great importance of placing contractors under money penalties. I believe I was one of the first consulting engineers—I am referring now to 25 or 30 years ago—to get an electrical contractor to agree to a penalty for failure to comply with the steam efficiency guaranteed in the specification. The author intimates that he thinks a contractor who is selling a 7,500-kw. generating plant might very well be called upon to agree to a penalty of £24,000 for each pound of steam per kw.-hour that the test figure exceeds the guaranteed figure. I shall be surprised, however, if he can persuade any contractor to agree to such a penalty. The mere mention of that figure, however, emphasizes how accurate the author believes his methods to be. If it were merely a question of dividing the number of pounds of steam used by the number of kilowatt-hours the process would not be without difficulty, because in conveying the watt-hour meter to the testing institution it might be put out of gear; but it is pounds of steam with a guaranteed steam pressure at the boilers, a guaranteed superheat, and a guaranteed vacuum; and taking all those things into consideration the contractor might think that it would be possible for a slight error of 0·1 lb. to arise and thereby affect him to the extent of £2,400. I may here say that I disagree with the author's estimate on page 109, where he says that £375 per annum for 1 per cent on the steam consumption capitalized on the basis of 8-years' life is equivalent to £3,000. The present value of £375 per annum according to the 5 per cent table is £2,424, and Mr. Merz would probably take the 7 per cent table, which would make the present value £2,238, or a total of about £18,000 for 8 per cent, against the author's £24,000. Whether it be £18,000 or £24,000, however, I entirely agree with the author on the great importance of attention to detail and have applied this to my own work. I have, for instance, supervised the testing of every set of generating plant added to the Leeds station since the start in 1893, of late years with the assistance of Mr. John May, and I have always considered that in order to ensure obtaining accuracy the most important step is to make perfectly clear, three weeks before the test is made, the exact conditions under which the test would be carried out. I always send the contractor very detailed particulars of the procedure: Part 1 consists of the conditions and details of the tests; and Part 2 of the specification guarantees, with the allowances to be made for any variation of the test conditions from the specified conditions. I ask the contractor to sign the conditions and to return them to me saying that he is in agreement with all of them. Under the heading "Procedure during the Test" it is stated that, "The following are nominated as the representatives of the parties. Have it perfectly clear who are the men on both sides who are going to carry out the test, otherwise men sometimes come in who are unauthorized. At least one week before the test deliver at the electricity works the apparatus scheduled on page 29 of the Specification," namely, water measuring tank, suitable inductive and non-inductive loads, two recording wattmeters, and so on. "Two days before the test fix all the apparatus, etc." "The day before the test, etc." "On the morning of Mr. Hammond.

* Journal I.E.E., vol. 47, p. 93, 1911.

[illegible] so on.

Mr. A. E. L. [illegible] [illegible] which I have [illegible]

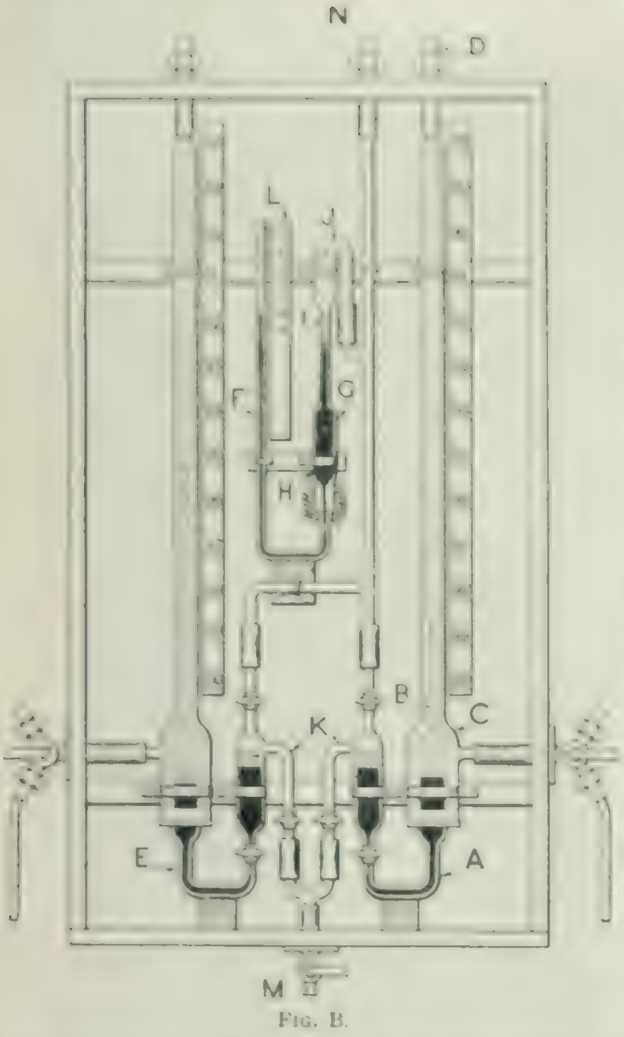


Fig. B.

[illegible] filled with mercury it is filled with coloured water. The outside jacket has water passing through it, which may be either condensed steam or part of the discharged cooling water. The water passing through the jacket will heat the central tube to the temperature of the condensed steam or circulating water as the case may be. [illegible]

[illegible] steam jet. I consider it would be in some [illegible] able to fix the surface of the condenser, but [illegible] per sq. ft. would be the safe maximum, the vacuum being [illegible] the contractor to state what the vacuum is going to be, so [illegible] denser, due merely to differences in the des[illegible] think that the value for K given by the author should be [illegible] siderable overload; this is perhap[illegible] The author stated that the air pum[illegible]

Mr. [illegible]

figure cannot be fixed, since for a given vacuum the absolute air pressure varies with the type of air pump. It is quite obvious that the air pressure in a steam jet would have to be considerably lower than the air pressure on a water jet, the total pressure in each remaining the same, this effect of course being due to the cooling effect of the water reducing the vapour pressure. Finally, I fully agree with the author that some standard form is needed for all tests, as unscrupulous manufacturers are willing to make guarantees which presumably they have no hopes of fulfilling, knowing quite well that without standard tests it is very difficult to prove the exact performance of the plant.

Mr. Woodhouse.

Mr. W. B. Woodhouse: If power-plant tests were usually carried out with the degree of accuracy that the author indicates, we should have much less literature from the makers of machinery. The important point to the central-station engineer is the overall efficiency; but whenever one compares the overall efficiency of a station with the individual tests of the plant enormous discrepancies are shown. Tests made of the efficiency of a complete station show that those discrepancies principally occur in the boiler-house. I agree with the author that it is unsafe to place too much reliance on the calorimeter test of the fuel, and that the proper way to find out what the fuel will do is to test it on a working scale. I want the author to go one step further in his analysis and divide up boiler efficiencies into three parts—the efficiency of the fuel, the efficiency of the furnace, and the efficiency of the boiler proper. I believe if that is done we shall get a much more accurate idea of what a boiler can do, and we shall get rid of many of those remarkable cases of efficiencies of over 90 per cent, which are impossible except by assuming a basis that is not practical. In a large number of cases there is something like 5 per cent of hydrogen as well as moisture in the coal, and the difference between the gross and the net heat value of that coal is of the order of 10 per cent. If that 10 per cent is credited to the boiler naturally it is possible to get quite a high efficiency, but the author points out that that should not be done. The author shows us that the plan which we should adopt in testing power plant is to test each part in detail with the assistance of those who know the possibilities of error in the measurements made. Many generating stations contain a lot of elaborate devices—indicating and recording instruments purporting to show what is happening to the plant—but the errors in those instruments are frequently of the order of 20 per cent, not only due to inaccuracies in the instruments, but because they are used in such a way that they cannot possibly give the true average results. The author's ingenious method of collecting flue gases is a case in point; here the sample is a fair average. The usual method of taking such a sample may give results which are hopelessly inaccurate.

Mr. Holehouse.

Mr. W. Holehouse: I have always considered that the cooling plant required a lot of attention, because being the "back end" of the power station it indicates what is really taking place. One of the greatest difficulties in connection with the cooling plant is to get the specified conditions. Within the last few years the conditions in regard to the design of a power station have altered considerably compared with those existing with reciprocating engines, and a great deal of attention has had to be paid to cooling towers in order to try and keep up with the requirements of the turbine. The point that ought to be decided—which is not mentioned in the paper—is the amount of water put in circulation. As regards the air pump, the amount of air that is allowed for has been mentioned, and also the cooling surface of the condenser. What is wanted in order to arrange the figures for the cooling tower is either to settle upon a given quantity of water, or to be content with fixing a vacuum that will result in a certain top temperature, and for the cooling-tower maker then to give a guarantee of the bottom temperature, modified in accordance with the conditions of the atmosphere. I would suggest that when installing a turbine of a certain size, considering that most of the auxiliaries are run by 3-phase motors, the amount of power that can be expended on auxiliaries and on a cooling tower should be set aside, and taken into account with the overall efficiency of the turbine and the best use made of it in obtaining the vacuum. If that power is utilized, then the quantity of water is fixed, its temperature varying according to the load on the turbine. The cooling tower should be arranged with a limit between the top and bottom temperatures according to the rating of the condenser. On that point, although I have had considerable experience with cooling towers, I am just as much at a loss to-day as when I started five or six years ago. Even if we consider one enquiry for a special job, it is surprising the different quantities and conditions that have to be dealt with. I should also like to refer to the atmospheric temperature and humidity. Although these figures are so much discussed, if we work within the limits of the condenser, that would not be a very big point; in fact, it would only amount to 2 or 3 degrees on the bottom temperature which would give a corresponding top temperature. The station would be run at a slightly higher vacuum at light loads, which, from the commercial point of view, would be better than trying to install a plant with a fixed top temperature and giving a bottom temperature beyond the limits of the condenser.

Mr. Boot.

Mr. H. Boot: I wish to confirm all that Mr. Hammond has said with regard to power-plant testing. One would almost assume from this paper that it is not the practice of consulting engineers to test plant under the very careful conditions that the author suggests. I believe that it is the practice of most engineers to arrange some considerable time before the tests are carried out exactly what is to be done, and also to get from the contractors, or to provide oneself with, a vacuum-correction curve. The author mentioned the question of penalties and bonuses, and seems to think that the giving of bonuses is due to the suggestion of engineers of large central stations. I am afraid the bonus question is one that has been forced upon us more by contractors than by central-station engineers, and quite fairly too, because naturally if the plant is better than they guarantee to supply, they ought to get more money for it. The author does not touch very much upon the value of the recording instruments in the station. I have found that the use of continuous-recording instruments for showing how far the plant has deteriorated from its original condition is of the greatest value. The author has not mentioned the testing of steam consumption by the V-notch method. My experience is that this method is extraordinarily accurate (often within ¼ per cent). The suggestion that turbine or other plant should run for six

[illegible] a test, it [illegible] great advantage. Although [illegible] from the purchaser's point of view it [illegible] that the manufacturer also [illegible]. Would the author suggest that [illegible] percentage of the price of the plant be paid [illegible]. Otherwise I do not [illegible] what would happen if [illegible] afterwards when the tests [illegible] and the contractors had [illegible] the money, the plant was not up to specification; it appears to me that it might lead to [illegible].

Mr. R. S. W[illegible]: [illegible] I [illegible] would be [illegible] to the extent of [illegible] per cent. as mentioned by a previous speaker. When reading this paper I could not help thinking that electrical [illegible] thermometers might well be used to [illegible]. I think that [illegible] thermometers can be. A [illegible] thermometer can be placed in the [illegible] and if it is [illegible] connected to a central switchboard a reading may be taken [illegible] similar thermometers can be placed in the [illegible] and in this way [illegible] of ladders can be avoided. I think this suggestion applies especially to the measurement of the wet and dry-bulb temperatures in cooling towers. Resistance thermometers would certainly avoid any risk of the proximity of the observer's body affecting the readings in the manner mentioned in the paper. I agree with the author as to the wisdom of not neglecting the commissariat when making long tests. It may be worth mentioning that hot coffee served on such occasions will be found a useful stimulant and may, perhaps, prevent the intrusion of inaccuracies in the test-sheet!

Mr. A. G. C[illegible] (*communicated*): On page 114 the author states that "errors due to change of resistance, unequal heating, and thermo-electric effects, are quite appreciable if the temperature approaches 85° F." Has the author made a mistake in the temperature and put Fahrenheit for Centigrade, or does he mean that this is the amount by which the temperature exceeds that of the surrounding atmosphere? No shunts of this class are usually designed for a temperature as stated in the paper. So far as it applies to thermo-electric effects his statement must surely be based on a very old system of shunt construction. Modern shunts do not have such defects, or if such defects exist, they are quite inappreciable. If the author used brass in conjunction with either "Constantin" or "Eureka," the construction may be such as to form a thermo-couple; but if other materials are used such as manganin and brass it would have been unnecessary to refer to this question in the paper. Unequal heating has not been observed in any tests that have been carried out. If, however, the author refers to the main joint connections where it is possible to get an uneven contact, then his small wiring is wrongly connected, as this difficulty has been overcome by most manufacturers for some considerable time. Stray fields are guarded against by having iron bases and cases. Certainly stray fields would be appreciable if the meter were placed in close proximity to heavy currents, but competent authorities would not suggest such a position. If, however, the meter is kept a reasonable distance away from the main supply and [illegible] connections [illegible] are [illegible]. I fully approve the author's suggestion [illegible] indicating [illegible], but I do not agree with his statement that "the tests [illegible] should be [illegible] and [illegible] most [illegible]." [illegible] It is suggested by the author that the test should be at unity power factor; [illegible] that such a condition is almost impossible, and if possible [illegible] the R.M.S. values of the generated [illegible] when the supply is [illegible] at the power station [illegible].

Mr. H. [illegible] (*communicated*): There is one point on which I do not agree with the author, and that is his method of measuring the output of a continuous-current generator. He prefers to use an ammeter and voltmeter except when the load is constantly [illegible]. I should put it the other way; I much prefer to employ an integrating meter unless the load is [illegible]. I think that except in rare cases the value of the output will not be obtained from ammeter and voltmeter readings with the accuracy [illegible] by the author. [illegible] the use of an integrating meter [illegible] the error due to the "human factor" in a test. Only two readings are necessary when a meter is employed, while on the other hand the use of indicating instruments involves a large number of observations, each of which is affected by the "human coefficient," one of the most troublesome factors to estimate, [illegible] with regard to its sign and value. The author's objection to the use of a continuous-current integrating meter is apparently due to its temperature coefficient. This difficulty can be overcome almost entirely, with certain types, if the resistance in series with the armature is made of copper instead of a low temperature-coefficient wire. Care must be taken that the series resistance is placed inside the meter case so that the temperature of the wire is the same as that of the disc. With reference to the measurement of the output of a 3-phase generator, the [illegible] is to employ two single-phase integrating meters. In my opinion this is a much better plan than the use of a 3-phase meter. In the former case each meter can be calibrated independently at the particular power factor and with the correct leading or lagging current. Also, if the load is not absolutely balanced the instruments can be checked afterwards at the actual loads obtained on the test.

Mr. F. F. F. B[illegible] (*communicated*): There can be no question as to the desirability of adequate [illegible] commercial testing in the case of large power plants operating at good load factors—in fact, in all the modern large power plants at home and abroad with which I am acquainted adequate provision is made for testing. I am not, however, convinced that in routine testing (as distinct from acceptance tests) a high degree of accuracy is either necessary or possible. [illegible] it is the [illegible] to employ [illegible] methods and [illegible] a high degree of accuracy in the calculations, so in routine testing it may be possible by great elaboration to increase [illegible] of the results. Frequently, however, it is [illegible]

Mr. Bisacre. commercial point of view to adopt rigorous methods in either connection. In acceptance tests the financial interests may be high, in which case an exceedingly accurate test should be aimed at, and for this purpose the services of a specialist are desirable. Dealing first with measurements of the efficiency of boilers. The efficiency is of course the ratio of the energy output of the boiler to the energy input, and if this fraction is to be computed from direct measurements the output and input must both be directly measured. The principal losses to which a boiler is subject are: (1) Loss of heat in the exhaust flue gases; (2) loss of heat by radiation from the boiler; (3) loss of heat due to unburnt fuel. Unquestionably the greatest of these is the loss due to the heat carried away in the flue gases. The amount of this heat can probably be calculated with reasonable accuracy provided two measurements and a chemical analysis are made. The measurements are those discussed in the paper, viz. (1) The determination of the CO_2 in the exhaust gases; and (2) the determination of the final temperature of these gases. The chemical analysis referred to is of course that of the coal. The paper contains very complete and valuable information in connection with the two measurements. The calculation (which involves assumptions as to the specific heat of gaseous mixtures) of the heat lost in the flue gases, if made on the basis of the two measurements referred to and the chemical analysis, assumes that no CO is present in the gases. Although CO is usually absent, this is by no means always the case; and if it is present in any quantity it must be allowed for. The curves given by the author for boiler efficiency are based on this assumption, which should be stated. Unfortunately, little information is given as to the means of actually determining by commercial test the remaining losses. With reference to the radiation loss, the author states that he is of opinion that the loss is no more than 3 per cent in a 20,000 lb. boiler, and that it may be taken as 2 per cent in the case of 30,000 lb. boilers and larger sizes. It would be interesting to have details of the experimental basis for this opinion. In tests where the result is desired to an accuracy of 1 per cent, there is room for no assumptions at all. Again, the author states that unburnt fuel can certainly be reduced to 10 or 15 per cent of the ashes, and may therefore be taken as 2 per cent. Presumably, in view of the accuracy aimed at, this point must be verified by an actual test; and in view of the nature of the residue its calorific value would probably be even more difficult to obtain accurately than that of the coal itself. Other points upon which the author has not touched in detail are the estimation of the output and input of energy. In the curves given, in order to arrive at the input of energy, coal of a certain calorific value has been assumed. The question arises, how is this representative calorific value to be obtained experimentally? In a boiler test in which, say, 10 tons of coal are consumed, probably no more than 5 lb. at the outside is ever tested in a calorimeter. This means that the input of energy is calculated upon the basis of tests carried out upon about 2/100ths of 1 per cent of the coal—and coal is of course a very variable substance. It is therefore of the utmost importance that the greatest care be taken in the selection of the sample. The author points out that he has found in a 10-ton truck sample of coal extreme variations in the quality sufficient to reduce the CO_2 from 14 per cent to 8 per cent, and the evaporation from 30,000 lb. to 18,000 lb. per hour. It is probable that in most boiler tests the assumed calorific value of the coal rarely represents the true average value. I have found that in practice there is always considerable discrepancy between the calorific values of the same coal estimated in different ways by different people. In my view, this measurement cannot be made with anything like a 1 per cent accuracy, and in most acceptance tests with which I have been connected it has been necessary for the various parties concerned to agree upon a method of sampling and testing which for the purpose of the test shall be deemed to give the calorific value of the coal. It is probably a case of averages. Contractors know approximately what their plant will do provided the calorific values of the fuel are estimated in certain ways. There is, however, no suggestion that the figure so obtained is necessarily correct. The idea of using a boiler as a calorimeter and working backwards to find the calorific value of the coal is ingenious, but does this not assume that the efficiency of the boiler is known? It is fortunate that since the output of a boiler may be estimated by subtracting the losses from the input, the latter quantity appears in both the numerator and denominator of the efficiency fraction, and consequently a fairly high error in the measurement of the input does not materially affect the calculation. For example, assuming that the input were 100 B.Th.U. and the losses 15 B.Th.U., the efficiency would be 85 per cent, while if a 10 per cent error on the low side had been made in the measurement of the input, the calculated efficiency would be a little less than $86\frac{1}{2}$ per cent. Thus a 10 per cent error in the calorific value only produces about $1\frac{1}{2}$ per cent error in the calculated efficiency. The efficiency can of course be ascertained by observing the output, but this is not an easy matter if very high accuracy is desired. If a boiler could be completely isolated and provided with absolutely tight valves, the steam delivered by it could be weighed after passing through a turbo-alternator; or, on the other hand, the water pumped into it could be weighed with great accuracy, and from observation of the pressure at the boiler stop-valve and the temperature there, the amount of energy delivered in a given time could of course be calculated. The accuracy of either method obviously depends, among other things, upon the amount of leakage of water either into or out of the system under test. Unfortunately, an actual boiler under test is usually one of a bank of boilers, and it cannot be isolated except by shutting valves. These are not always tight, and elaborate tests (or assumptions) have to be made, or else all the valves must be provided with solid partition discs, which introduces a good deal of difficulty. In connection with condensers, it would be interesting to have the author's views as to how the amount of the circulating water is to be measured. Frequently this is done by estimating, from an assumed turbine efficiency, the amount of heat per lb. in the exhaust steam. The temperature rise across the condenser is then measured, and this in conjunction with the estimated quantity of heat supplied to the circulating water enables the calculation to be made of the amount of the circulating water. It would seem that such an estimate can only be approximate, for the following reasons: (1) Assuming the efficiency of the turbo-alternator to have been measured

[illegible] water meter would need to be [illegible] There is no room for any extrapolation in arriving at such a "standard" against which the [illegible] method is to be compared. It seems to me that [illegible] circulating water employed to-day when one has arrived at an accurate method. The author's statement that the proximity of an observer to a thermometer was found to [illegible] radiation from the observer's face is quite sufficient to vitiate a reading if the latter is not taken promptly, is significant and confirms my view that in ordinary routine testing [illegible] routine testing, the observations have to be taken by the personnel available, and if the thermometric readings are [illegible] anything like 2° F., it would appear that we have a long way to go before we arrive at tests accurate to within 1 per cent. As previously mentioned, acceptance tests are on a totally different footing, and in such cases it is highly desirable to make the most accurate test possible. The utmost pains are well repaid.

Mr. W. M. [illegible] with the larger aspects of the question. He says that, for instance, in a large power station much can be done which would be impossible in a small one. I think there can be no difference of opinion on that point. I have mentioned in my introductory remarks that the practice on which I drew for the matter of this paper was not the work of one man but of many men, and the result of much discussion. That can only occur in a [illegible]

[illegible] the ordinary [illegible]

The question of [illegible] any body of men who [illegible] that the engineers have [illegible] that they [illegible] could get [illegible] ing with the running of [illegible] In my experience such a course has resulted in our being able to do things on service load that we should never have been able to do [illegible] I have never found in the long run that it has interfered with their station duties when once the conditions—as [illegible] time beforehand to allow them thoroughly to think over what the situation actually means in running. Given a [illegible] met with any case yet where the operating engineer has [illegible] testing without unduly interfering with his ordinary duties. Mr. Chattock also raised the question, which [illegible] plant when he only looks at the [illegible] It [illegible] because, as Mr. Chattock suggests, the s[illegible] has to [illegible] than the [illegible] is the man who has to look after a huge station and all its interests to do all this? It is a very difficult question. [illegible]

[illegible]

engineer, can hardly be expected, in view of the diverse duties of such a post, to have specialized in some particular technical branch of the work, as he would thereby be liable to lose grip of the general control of the concern for which he is responsible."

I think that is quite the correct position to take up, and that it is partly what Mr. Chattock has had in mind. His suggestion that the Engineering Standards Committee should take up the question of some forms of standard specification in order to help such very busy men is a good one. He suggests that I have not done so. I have, however, done a little in that direction in the paper; for instance, in connection with condensers and air pumps. I believe there is no part of the paper that has so far met with more criticism. Any attempt to restrict the manufacturer seems to arouse antagonism. Therefore it is not my place, even in a paper like this, to do more than very gently hint that standards may be laid down without interfering with the contractor's freedom in acquiring merit as regards his apparatus. Mr. Chattock brought home another point, as did Mr. Hammond, that all corrections should be provided for in the specification. I believe that is now becoming the general practice. I think the contractor is finding that after all it is best from his own point of view to see that these corrections are included at first.

Mr. Paterson entirely disapproved of any assumptions as to totally enclosed switchgear. The practice in the North has been to test before enclosing the gear, if not on the actual transformers, at any rate on some made from the same patterns. Mr. Paterson would suggest that the meters must be tested in conjunction at the same time. If that is so, it means taking the switchboard to the National Physical Laboratory—which I understand one enterprising engineer in London is now doing (it is an exceedingly compact type of apparatus)—or else having separate sets of gear. These may be placed in a busbar sectionalizing panel or in a special section between the switch and the busbars, or else on the machine side of the gear, which latter interferes with the protection scheme. There are innumerable difficulties, and it is a case where engineering considerations must take precedence of testing accuracy.

Mr. Scanes' gauge is one of those simple things which we do not think of until somebody else has done them. With regard to fixing the condenser surface, I hope that when condenser manufacturers have studied this clause a little more they will find that I have really gone a long way towards suggesting a standard in condenser practice, and at the same time have left a large loophole for individual merit. As I have said, however, from my point of view it is not a procedure which will meet with much encouragement.

I thoroughly endorse Mr. Woodhouse's remarks on boiler testing. It is a fact that a figure which is near 100 produces in some minds a sense of satisfaction. I have tried to point out in other directions the fallacy of trying to make a physical standard, which is an ideal thing, conform with the conditions under which some particular piece of apparatus has to work in order that one may be able to write down on paper a figure which is near 100. There is no better example of that than the efficiency of air compressors. When these were first introduced they were single-stage compressors, and an adiabatic efficiency was always quoted. Then pressures increased, and an ingenious engineer invented the 2-stage compressor and quoted on the adiabatic overall efficiency, obtaining a figure of over 100 per cent. The only basis on which to quote was of course the isothermal efficiency, which is the physical standard; an absolute and unattainable ideal. It is exactly the same with boilers if an attempt is made to show a higher efficiency by taking the lower calorific value. It does not matter what the figure is so long as it is perfectly clear what is meant and that it means the same to everybody. Mr. Sel

Mr. Holehouse's remarks did not bear altogether on testing, but they did bear very much on what Mr. Chattock said as regards standard specifications, and the two subjects are inseparable, because there is little use in testing unless the data obtained are utilized in the next specification. The question of the cooling-tower temperature-difference is absolutely settled by the condenser. The top and bottom temperatures increase and decrease together, and differ only in proportion to the amount of heat that has to be removed. The question between towers as regards their effect on power-station economy is: what are those two temperatures to be? Are they to be 100° F.–90° F., or 90° F.–80° F.? This appears to contradict my remarks in regard to testing cooling towers on a fixed top temperature; it is, however, purely a testing point, which is not the same as an operation point. I made the remark for this reason, that if two towers differ fairly wide in merit their lower temperatures may be at the same time rather near together from a testing point of view while giving the same range of cooling. To test them by comparing the bottom temperatures for the same heat dissipation requires great care and exceedingly delicate instruments. Therefore I have put forward a method of comparing towers which is a testing method and nothing more. This is quite different from what Mr. Holehouse said. I entirely agree with him that practice has so changed since steam turbines replaced reciprocating engines that the point of view from which towers should be regarded requires very considerable revision. The quantity of water to be cooled is now from 60 to 70 times the amount of condensed steam. I think the specifications that are asked for are not always in conformity with the actual requirements of the plant in everyday working.

Mr. Boot and Mr. Hammond both dealt with the financial aspect of the question. Of course that is not the subject of the paper. I stated at the beginning that my calculations were intentionally approximate. I quite appreciate Mr. Hammond's point both in regard to present value and also as regards Mr. Merz's 7 per cent, but it does not alter the point which I tried to make as to the financial importance of accurate testing, and that is all I wish the example to do. I do not follow Mr. Boot's remarks in regard to payments to the contractor, nor do I understand how they enter into the question. The contractor will not get his 10 per cent retention money until the end of the 12 months. All I asked was: is it better practice to test the plant immediately it is put into service and then at the end of the 12 months, or is it better to test it six months after it was started up? I do not see that it makes any difference to the terms of payment,

[illegible] far seen little evidence that previous experience has been [illegible] country, who are in my opinion likely to have the widest experience in this direction, and their replies support [illegible]

[illegible] been raised with reference to the design of other instru- [illegible]

As regards the instruments themselves, I cannot at [illegible] in regard to [illegible] instruments. The [illegible] equation is largely one of [illegible] regards stray fields, it must not be hastily assumed that [illegible] instruments are protected against.

Taking now the alternating-current measurements, on [illegible] there is room for a difference of opinion, but my preference

[illegible] matically sampling the whole of the coal to be tested, and [illegible]

[illegible] water, unfortunately [illegible] about 20 per cent in the best cases and the error in the efficiency of the alternator is therefore immediately divided by five, in the manner indicated in Mr. Bisacre's previous [illegible] meter. The point [illegible]

The limit of accuracy with which large quantities of [illegible] like that to be found in the [illegible]

Birmingham Local Section, 25 November, 1914.

Mr. R. J. Kaula: From a manufacturer's point of view, I think there is ample scope for independent testing and for the standardization of methods of procedure in testing steam power-plant. With the large units now being installed it is practically impossible to carry out exhaustive works tests, and designers are mainly dependent on tests carried out on site for the verification of their calculations. Consequently, the accuracy and completeness of such tests are of paramount importance to them. This remark applies even more forcibly to condensing plants than to steam turbines, as it is not feasible to carry out works tests on condensing plants even in small sizes. I do not know whether the author intends to imply that tests can be relied upon to give results within a degree of accuracy of 1 per cent. With the instruments and apparatus generally available for commercial testing, I think that this margin would be too narrow, and it is for this reason that turbine makers now call for a margin of 2½ per cent either way before a penalty or a bonus is inflicted. The author does not refer to the use of recording apparatus for measuring condensed steam. This form of apparatus may not represent the ideal form for testing purposes, but it is certainly most useful in providing a permanent check on the consumption of the plant and as an indicator of any increase in the consumption. I fail to see why the author should suggest specifying the surface of condensers. The influence of surface in itself is very small. I have known cases where it was necessary to re-arrange the tubes in order to attain the required vacuum, and, in doing so, certain sections of them had to be removed altogether, *i.e.* the surface was reduced, and results were obtained which were found impossible to attain with the larger surface. I think that purchasers should leave the contractors a free hand to design the condenser with the smallest surface for which they can obtain the results which they are prepared to guarantee, and if the purchaser considers that the nature of his cooling water is such as to call for a liberal margin, he can specify readily that the guaranteed conditions are to be obtained with a certain percentage of the tubes plugged up. This seems a more reasonable method of providing a margin. I consider that the author's figure for K (heat transmission coefficient) is too small for modern practice. $K = 550$ is a figure which represents more closely the results obtained in everyday practice, and not when the condenser is new, with a water velocity of 6 ft. per second. It should also be pointed out that K varies considerably with the velocity of the water. I fully appreciate the author's praise of the combination of a vacuum augmentor and an Edwards air pump. At the same time, there is very little doubt that with the gradual improvement in rotary air-pump systems of various types, one may expect to obtain an equally satisfactory power consumption, but I think that this stage has not yet been reached. The use of a vacuum augmentor in conjunction with a rotary air pump, *i.e.* in conjunction with a water jet, has its advantages, but its value is not so great as in the case of an Edwards pump owing to the increase in the air capacity of a rotary pump due to reduced vacuum not being equal to the corresponding increase on an Edwards pump. It is difficult to determine the actual quantity of air which should be allowed, and I think it would be worth while carrying out a series of tests in various power stations to arrive at suitable figures which might be standardized and to which both turbine makers and condenser makers would be called upon to work. The experience of my firm shows that 6 to 7 lb. of air per 10,000 lb. of steam should be ample for sets of about 1,000 kw. rating, and that half this figure could be obtained with plants of 8,000 to 10,000 kw. rating. Naturally, allowance has to be made if the condenser is not placed in close proximity to the turbine, and, similarly, very much larger figures should be used for mixed-pressure work. There is probably much to be said in favour of the author's proposal to carry out official tests after six months' operation, but in practice it is found necessary to carry out these tests as soon as possible after the plant has been set to work.

Mr. E. P. Hollis: When one enquires closely into the sources of inaccuracy in power-plant testing so many are the sources of inaccuracy, intentional and inadvertent, that few engineers place implicit reliance upon their results. Many of the sources of inaccuracy are extremely elusive. Often enough, however, the engineer who is meticulous about his instruments will innocently vitiate results by failing to detect a leaky boiler-tube or valve. It always seems to me that it would be of invaluable assistance to engineers engaged occasionally on testing work to have a complete list before them of the precautions to be taken and the dangers to be watched for. Some of these precautions are generally realized, but there are some which are not so well known. Particularly does this remark apply to the larger sources of error, such as a leaky boiler-tube which I have mentioned, and the leaky condenser-tube, an error which only shows itself near full load of steam. I will give a few typical precautions to be taken. One is that all thermometers should have the same stem exposure as that on which they were tested. Another is the measurement of the thermo-electric voltage effects in instrument leads from shunts with low pressure-drops. Incidentally when shunts are used errors have been known to arise owing to the distribution of the current in the shunt being different when it was at work from what it was when tested. Again, there are such precautions as that of blowing down the boiler gauge-glass when the test demands that the water level should be read. It is well known that the height of the water will increase owing to the difference in temperature between the water in the glass and that in the boiler. Power factor always seems to me to be an important feature in testing. Most plants are constructed for a definite power factor, and it seems proper that they should be tested at that power factor. The author thinks otherwise. Is this because of the difficulty of providing a low-power-factor load? I do not subscribe to the author's views as to the exclusion of sound signalling. I appreciate his contention, but it is important to realize the individual characteristics of the eye and the ear. The ear picks up sounds irrespective of their direction; the eye must be looking at the source of the signal or the latter may be missed. Visual signals should therefore be always supplemented by audible

[illegible]

[illegible] owing to the devel[illegible] have [illegible]

[illegible] In fact in any large continuous-current generating station [illegible] elaborate arrangements. If this be possible the engineer in charge will be encouraged to test periodically all his instruments and secure agreement between the various records in his log sheet. After all, accurate special tests are very useful, but what is really wanted is accuracy under [illegible] by which the electrical energy is sold are 2½ per cent or more wrong. The author refers to the temperature coefficient of continuous-current watt-hour meters. Many such meters have a large temperature error, but I should like to ask the author whether he has had experience of the Aron clock-type meter in this connection. As far as I am aware this meter is the only one in which all errors such as those due to temperature, friction, etc., have been scientifically eliminated. I cannot agree with the author's recommendation in regard to 3-phase measurements. The method of conveying the whole equipment of current and potential transformers with their instruments to a testing authority is very cumbersome, and, morever, I should not have very much faith in the results which would sometimes be obtained. It is very good to get instruments tested by testing authorities from time to time to make doubly sure

[illegible] considerably at lower power fa[illegible] to test at the average power factor existing under the [illegible] ratus for obtaining an artificial inductive load for alternator testing was described in a paper read by Mr. R. K. [illegible] steam condensed per hour. The ample area [illegible] time without diminution of vacuum due to fouling. This [illegible] and I suggest that the increased cost would be better de- [illegible] [wou]ld be better than running the condenser in a dirty and consequently less efficient state. It is doubtful whether the buyer would be any better off if he were to specify the amount of cooling [illegible] mine the capacity of a condenser; the proper d[illegible]

[illegible]

Mr. Walshe. side, the author mentions the electrical resistance method. This method is very convenient and exact and deserves to be better known. The apparatus required is very simple. A glass U-tube 3/16 in. in bore and $7\frac{1}{2}$ in. long in the leg when filled with a pure sample of condensate and connected to a "Megger" will give a reading of about 40 megohms. If the sample is diluted with a very small quantity of cooling water the resistance is lowered very considerably. The addition of 1 per cent of cooling water drawn from the Birmingham Canal lowers the resistance to 12 megohms. There is an excellent instrument on the market specially designed for this work which has been described in a pamphlet by Mr. S. Evershed entitled "The Dionic Water Tester."

Mr. Mills. Mr. E. A. MILLS: I cannot understand why it is the usual practice to state the efficiency of a boiler without taking into account the equivalent amount of steam required to drive the auxiliary plant. To obtain the normal hourly evaporation of a boiler this steam amounts to about 2 per cent, and may even be as high as 4 or 5 per cent. The capitalized running costs of the auxiliary plant of a boiler of, say, 30,000 lb. normal evaporation per hour is approximately 20 to 25 per cent of the cost of the boiler. It is therefore rather surprising to find this point ignored in the report of the Committee on Steam Engines and Boiler trials recently issued by the Institution of Civil Engineers.* I do not agree with the author that the higher calorific value of the coal should be used to arrive at the efficiency of a boiler, because the coal has the lower calorific value when it is introduced into the stoker; and since any hydrogen contained in the coal passes away up the stack in the form of steam it is therefore the lower value which takes into account the ash and moisture as received, and this is the figure which is of most interest to the engineer or buyer. I am practically in agreement with the author as regards the percentage radiation losses referred to on page 111; my experience, for the larger size boiler mentioned, is 4 to $4\frac{1}{2}$ per cent for radiation and unburnt fuel. I have found that the average amount of CO_2 in boiler-houses over very long periods is between 4 and 6 per cent, the samples of the gases being taken at various times during the day and night. The author's suggestion that the buyer should specify the condenser surface is correct. The present tendency on the part of the designer of condensers when the surface is not specified is to make the size of the condenser rather small. I do not infer that this is done intentionally, but in a number of cases the buyer is to blame for not giving sufficient information about the quality of the circulating water. One of the chief considerations in fixing the tube surface of a condenser for a given capacity of plant is the cost of cleaning the tubes and the difficulties that may arise owing to the plant having to be out of commission for this purpose, especially in the case of a large set and when the stand-by plant of the station is small. Hence the desired surface ought always to be stated by the purchaser. I shall be glad if the author will explain whether the expanding nozzle to which he refers in connection with centrifugal pumps forms an integral part of the pump, or does he refer to short pipes such as are sometimes placed between the pump and the condenser? I think the reason Mr. Mills. why fans have never a very high efficiency is that they seldom work under the conditions for which they were designed. The method of testing a fan which is described in the paper is that adopted by many fan makers. I do not, however, favour this method because a sudden change of conditions is experienced at the entrance of the nozzle; a more suitable method would be to arrange a nozzle which is readily adjustable and whereby the change of conditions can be carried out gradually and smoothly.

Mr. W. M. SELVEY (*in reply*): In reply to Mr. Kaula, my Mr. Selvey. opinion in regard to the usual accuracy of commercial testing is given in the paper as 3 to 4 per cent, and I suggest that this is not sufficient in view of the nature of bonus or penalty clauses and the improvements aimed at by manufacturers. I did not deal with routine testing except in suggesting the complete acceptance test as the basis with which to compare future routine tests. As regards the surface of a condenser, I have no reason to change my opinion after having heard the arguments put forward by many speakers. The value of K will allow for the way in which the surface has been utilized, and although K is not really a constant, but depends to some extent on the actual temperatures, the latter now vary in turbine work between such narrow limits that I think the general use of this term is to be recommended. The value given by Mr. Kaula is very uncommon below an absolute pressure equivalent to 2 in. of mercury, which is the figure that might now be aimed at for all large sets having cooling towers, and is still more uncommon when the pressure is below $1\frac{1}{2}$ in., which latter pressure is now very commonly obtained both at sea and near large estuaries. With my scheme it will be necessary to state the vacuum obtainable for the specified surface, instead of stating the surface recommended to give a certain vacuum. It will also tend to keep up the size of air pumps, which I think is still good practice. The question of how best to utilize the surface is outside the scope of the paper.

Mr. Hollis raises many questions which occupy the attention of testing engineers, and he shows how many pitfalls there are. This is the best possible argument for specialization in the subject. After years of continuous testing I have rarely run a test without coming across some point or other worth noting for future guidance.

In connection with signalling it should be stated that red lights are used, and that if a sufficient number are provided and a clear programme is drawn up, the method is found to work well. For warning a scattered group of observers, an audible signal is doubtless the best, but it requires to be very powerful; and if it has to be repeated every five minutes for simultaneous readings it becomes rather a nuisance. I naturally approve strongly of routine testing by the station staff, but for such tests it is not always necessary to take all the precautions or readings which would be required for the acceptance test; the latter will be found a very good basis with which to compare future routine tests. It is surprising, however, the number of points in which a mistake may be made in routine testing.

Dr. Garrard's remarks appear to be almost a counsel of perfection, and I only know of Mr. Fawssett's laboratory, a few of our universities, and the National Physical Laboratory which would meet his requirements. Perhaps,

* Report of the committee on tabulating the results of steam engine and boiler trials. *Minutes of Proceedings of the Institution of Civil Engineers*, vol. 195, p. 265, 1914.

[illegible]

Newcastle Local Section, [illegible]

[illegible] stating that considerations affecting the obsolescence of plant are of the utmost importance. There are few machines in this country 15 years old which are now [illegible] are made which can be relied upon to be correct within 3 [illegible] example of this liability to error, as is also the ratio between [illegible] other examples, *e.g.* the determination of the parallax of the [illegible] because the instruments would be to some degree different. [illegible]

as accurate as possible. [illegible]

Mr. Fawssett. value, but the tests should be periodically repeated afterwards, as 1 per cent of the annual coal bill is disproportionate to the cost of such a test, and a greater deterioration than 1 per cent might otherwise escape detection. In regard to the statement on page 114 that time should not enter into water *versus* energy measurements, continuous-current measurements depending on the mean of many readings of indicating instruments and time make such readings doubly inaccurate compared with the simple integrated measurements on 3-phase circuits. Alternating-current meters lend themselves to remote control much more easily than continuous-current ones, and for an accurate test in either case, especially the latter, it is important to keep the actual recording instrument unaffected by stray fields and excessive temperatures. I suppose the best continuous-current meter is the Aron type, and in the larger sizes suitable for this sort of work the meter would be shunted. The temperature-coefficient question then becomes acute. On the other hand, in the smaller sizes, such as might be used on a high-voltage supply, with straight-through current coils, it is difficult to ensure that heavy leads cause no strain on the coils and so upset the calibration. In a recent case three meters were so affected to the extent of 2 per cent. The trouble is a very insidious one. Certainly unity power factor is preferable on the score of accuracy, but many machines have to give their output with a large wattless component. I may perhaps give one instance of how low power factor complicates matters: the power-factor compensation of a 3-phase meter when once set depends on two other quantities which may be variable during the test: (1) The phase angle of the current transformer may vary with the primary load and also with the secondary loading. (2) The effect of temperature on the compensator. The first variation can be eliminated in calibration, if the current transformer is not deficient in ampere-turns. This is not so, however, in some switchboard types, which is presumably the reason why the author specifies unity power factor under these circumstances. The temperature effect is more serious. Suppose a certain change of temperature (*e.g.* 10° F.) disturbs the phase compensation 0·5 degree. At unity power factor this change is neutralized in the two elements, but at 0·8 power factor one element works at 7° lag and the other at 67° lag, the consequent change in the values of the cosines of the angle of lag totalling 0·7 per cent, or many times the degree of accuracy aimed at. The foregoing remarks may show that the electrical measurement is not so simple as the author suggests; yet, as he says, no measurement can yield happier results. A case in point was a series of tests on a large turbo-alternator at unity and various lagging power factors. The increased steam consumptions with decreasing power factors checked well with the expected increased machine losses, which being the small difference of two big quantities was a very rash measurement to undertake. I am in entire agreement with the author in his suggestions and conclusions as to the personnel of the necessary staff. Undoubtedly sincerity and keenness are much more valuable than technical brilliance. Such is certainly my experience of the last 10 years.

Mr. Ellis. Mr. H. S. Ellis: In regard to the cost of testing, I think, as Mr. Stoney suggests, that it would be useful if the author would give us an idea of the cost of thoroughly testing a 2,000, 5,000, or 10,000 kw. turbine plant. It would be almost impossible for the ordinary staff in a small power station to make such tests. I control a station supplying about 5 million units a year and I should demur to calling upon my staff to do this work. The cost of setting up the instruments would be excessive. So far I have been able to arrange for the official steam consumption and load tests to be carried out at the contractor's works, which arrangement has always proved to be very satisfactory. In the case of a power company like the Newcastle-upon-Tyne Electric Supply Company, who distribute something like 200 million units per annum, it would seem, however, quite a simple matter. The subject, although very interesting, is one which comes within the scope of not more than about half-a-dozen men in this country. In regard to the question of impurities in the condensate, I am of opinion that they can be measured. If, however, the plant is properly arranged I think that they should not occur. Nothing but pure steam should come over from the boilers. In this connection I may say that there has never been any hesitation on the part of the Tudor Accumulator Company to allow us to use water obtained in this way for their batteries.

Mr. Baker. Mr. H. H. Baker: We all, in this district, most certainly appreciate the importance of testing, and are always hearing about doing a little better next time. I wonder what the standard will be when the ideal of 99·5 per cent of the possible is attained. I think on the other hand that it is possible to go a little too far. It is useless getting increased efficiencies if the machines are to be complicated and their reliability thereby affected.

Mr. Jackson. Mr. J. W. Jackson: We on the North-East Coast have realized what engineers all over the country are feeling, namely, the necessity for having an expert who can deal with all the little accidents that are liable to occur in the testing of a power station plant. These are so numerous that no station engineer can be on his guard against all of them. The question which the author raises in regard to load factor is one that I am afraid will be always with us. The curves dealing with the efficiencies of turbines and the amount of CO_2 are valuable and precise. There is a point in regard to reducing the flue gas temperature to 350° F. I have seen flue gases reduced to 250° in normal working with an economizer, and this with a reasonably high proportion of CO_2. This would appear to indicate a very high efficiency, approaching 80 per cent, in commercial working. I should like to ask a question as to the amount of power taken by the Edwards air pump. This is given as the smallest amount of power normally taken when working in conjunction with a steam jet. Is it not true that this is the same as the power taken by an ordinary "kinetic" pumping set? With reference to cooling towers, not only can varying temperatures occur throughout the base, but if there is a pipe of large diameter leading away from the tower for a distance of 20 ft. it will be found that there is a difference in the temperature between the two sides of the pipe. The contractor should be allowed to attend to faults on a turbine, the steam consumption of which is to be tested if such faults are due to the amount of solid matter collected in ordinary working. If, however, they are due to delicate construction he should not be allowed to put it right.

Mr. Baxter. Mr. W. Baxter: The author refers to an accuracy of

Mr. Stoney. 1 per cent, but as the manufacturers in this country will guarantee an accuracy of 1½ per cent I do not see why we should go to the expense of making such very accurate tests.

Mr. Beard. Mr. J. R. Beard: I was glad to find the emphasis given to the necessity for organizing tests. [illegible] The method, mentioned by the author, of testing water [illegible] efficiency of fans. If some simple method of determining [illegible] improvements would be effected.

Mr. Selvey. Mr. W. M. Selvey (*in reply*): In reply to Mr. Stoney, the [illegible] From the current issue of the *Electrical Times* I find that the load factor at West Ham is [illegible] per cent, at Stepney [illegible] per cent, at Bermondsey [illegible] per cent, and at Poplar 25·61 per cent, and I expect that the load factors at these places will be still higher in a year's time. I agree that a 2½ per cent margin involves a risk to a contractor who does not take special care about testing. I wish to make it perfectly clear that in almost every case all that the engineer can do on site is to try and reproduce the conditions under which the apparatus was checked in the standardizing laboratory, and to transport the apparatus and instruments from the laboratory to the site without their suffering any injury. The standard of accuracy must always be set by the standardizing institution. The measurement of vacuum is certainly open to errors, but, generally speaking, if gauges on opposite sides of an exhaust pipe differ it is a reason for suspecting the gauges. Differences which have been measured at various places in a well-designed exhaust branch did not amount to 1 in. water gauge. I quite agree with Mr. Stoney's remarks about avoiding corrections if possible, and also as to their reasonable magnitude.

In reply to Mr. Fawssett, we are, as he well knows, still [illegible] in the alternator output for a constant steam consumption. [illegible] manipulate.

[illegible] the difficulty of measuring [illegible] the circulating water is fresh is not a light one. It is quite easy to detect leakage, but that is very different from measuring it accurately.

[illegible] interested. In visiting large power stations which have already a skilled staff the chief could probably manage with one assistant, or perhaps even alone. The writing up of the results, however, needs two men. In [illegible] the subject, it is necessary to bear in mind the amount of [illegible] calculations which have to be made after the test.

In reply to Mr. Baker, I quite agree that if efficiency is to be gained at the expense of reliability it is too costly, but it must be remembered that this is the trend of progress. Mechanical perfection always lags behind increased efficiency, but its rate of progress in the long run is the same.

With reference to Mr. Jackson's remarks, although I have seen many figures for modern air pumps, I am afraid I have no figures for actual tests of Edwards air pumps where the quantity of air actually removed was measured, and so I cannot give a rigid comparison. I based my remarks on the usual input per kilowatt of steam plant. I am glad to have his confirmation of [illegible] obtained.

In reply to Mr. Beard, I think that it is not very difficult to measure the efficiency of a fan, and it is carefully done when the fan becomes a turbo-blower, *i.e.* when it is large enough to make it worth while from the user's point of view to look into the question.

Manchester Local Section, 1 December, 1914.

Mr. Pearce. Mr. S. L. Pearce: Some few years ago Messrs. Merz and McLellan read a paper on power station design* in which [illegible] the importance of keeping down the [illegible] "cost of production." The present paper, on the other hand, emphasizes the importance of obtaining the [illegible]

* C. H. Merz and W. McLellan: "Power station design," *Journal I.E.E.*, [illegible]

Mr. Pearce. most economical plant with a view to reducing the "running cost" component of the total "cost of production." This is in view of the advance made during the last few years in obtaining higher load factors. The author refers to the question of obsolescence, and considers that this factor has not been sufficiently seriously treated by supply authorities up to the present. This may be so, but at any rate I think most large municipal undertakings to-day recognize the importance of providing something more than the statutory sinking-fund payment prescribed by the Local Government Board. They may deal with this matter under different heads and under different names, but the clear intention is to write down the existing plant within a term of years very considerably less than that allowed by the Local Government Board. This is undoubtedly provision for obsolescence. I entirely disagree with the author when he states that no longer that 8–10 years should be allowed in regard to plant rated at less than the particular output stated in the paper. I think he must have in mind not only the very large generating stations which exist to-day in connection with, say, the North-East Coast electricity supply, but other undertakings of a similar magnitude. Obviously his remarks cannot, and ought not to, apply to the majority of undertakings (municipal or otherwise) that exist in this country to-day. How many undertakings are there which have installed turbo-alternator sets of 5,000 kw. rating and upwards. The probability is that 500 kw. is very much nearer the mark in the case of the majority of supply undertakings to-day. Further, I should not like it to be thought that the Institution endorses the author's opinion that 8–10 years is a sufficient life for a plant of even 5,000 kw. rating, and that the cost of such plant should therefore be written off within that period. This has certainly not been the policy of the large power companies in the past, and with regard to the larger municipal undertakings I say advisedly that it would be absolutely impossible to carry on the undertakings if the term of 8–10 years were to be adopted, instead of 15 years. The latter is, in my opinion, a fair measure of life for the plant. Any reduction in this direction is simply tending to put on the present generation the double burden of writing down existing plant and providing new plant out of revenue. I confess I do not follow the author in the next paragraph, when he states that within the next 10 years the significance of "load factor" will have disappeared. It seems to me that this is entirely contrary to the author's main argument in favour of the predominance in the future of the "running costs" over the "capital costs" of production. The reduction of the "running costs" must, and does in point of fact, vary with the load factor on the generating station, and if the significance of the load factor is to disappear, then the author is arguing against his own case, which is in favour of emphasizing the importance of obtaining economical plant and so reducing the "running costs." I think there must be some confusion in the mind of the author on this particular aspect of the question.

There are two points in the section dealing with boilers and economizers that I wish to comment upon. The author argues, I think rightly, that the boiler should be designed having regard to the calorific value of the fuel intended to be burnt. He says that if the boiler is designed for bad coal, and is fed with good coal, no brickwork will stand. I think he might also have added the words "or grates." With regard to the temperature at the back of the boiler and economizer respectively, I agree with his figures. For a dry slack of about 12,000 B.Th.U. calorific value I think the average temperature at the back of the economizer is about 350° F., and at the back of the boiler 550° F., that is to say there is a fall of temperature of about 200 degrees across the economizer. The figures for a coal of higher calorific value, say 13,500 B.Th.U., would be respectively 400° and 600° F. I think most engineers will agree with the author's remarks in regard to coal testing and the necessity for employing a fully qualified chemist in the station. At the top of page 114 the author points out that the vacuum should be measured at the exhaust flange of the turbine, although I take it he means in the space immediately above the tubes. This is an important point. The loss of vacuum between the last row of blades and the steam space of the condenser should be reduced to an absolute minimum, and that factor depends upon having a free exhaust. On the design of the exhaust end of the turbine depends the degree of vacuum to which the turbine will respond; therefore so far as the turbine is concerned the controlling vacuum is that of the steam space immediately above the tubes, and to record the vacuum in any other part of the condenser is practically futile. Another important point is to test the loss of vacuum between the steam space of the condenser and the air-pump suction. That should also be reduced to an absolute minimum. I think it would be a good thing to specify that the contractor should fill in this figure in his tender, and that when the plant is to be tested, a test should be made to see how far that guarantee is conformed to. The importance of making tests for vacuum between the top and bottom of the condenser is not always appreciated. Broadly speaking, it serves as a very good indication of the efficiency of the air-withdrawal plant. If the air pump is not doing its work, the effect of the excess air in the condenser will be a lower temperature of the condensate and an inefficient cooling system, owing to the air insulation round the condenser tubes. Another test that the author has not referred to should be the measurement of the difference between the exhaust steam temperature and the temperature of the condensate. A small difference between these readings would be a good indication that there is a certain "furring" action taking place inside the condenser tubes, and a big difference on the other hand would be a pretty sure indication of the presence of a serious air leakage. I quite agree with the author in emphasizing the value of having ample cooling surface. I do not find in this paper any reference at all to the advantage of having the recording testing instruments centralized. In several of the large modern power stations in this country which I have visited this seems to be quite a feature.

With regard to the question of electrical meters. In a previous paragraph the author states that measurements should be purely a question of matter against energy. It is therefore unfortunate that he immediately departs from his ideal by condemning the use of watt-hour meters. Continuous-current watt-hour meters are admittedly somewhat unsatisfactory, but unless the load is absolutely steady I doubt whether there would be any gain in the accuracy

[illegible] than might naturally be expected. They should be fixed horizontally and, if built up of strip, with the plane of the strips vertical in order to facilitate cooling. The connections must be so made as to ensure that each end of [illegible] carry nearly twice the current required, with a correspondingly higher voltage drop. In the case of high-tension 3-phase circuits, it is advisable not only to use special instruments, but also if possible independent current and potential transformers (*i.e.* used for testing purposes only). An obvious alternative to sending such [illegible] cate the use of two single-phase watt-hour meters instead of a polyphase meter on all 3-phase tests, as much greater accuracy is thereby ensured, there is less possibility of errors arising, and more information is obtainable. All apparatus should be checked both before and after the [illegible] figure as the possible limit of error from absolute accuracy [illegible] efficiency tests should always be run at unity power factor, [illegible] value.

I fully endorse the author's remarks with regard to the excellent results that can be obtained by the use of the Edwards air pump, with or without a steam augmentor, and from the point of view of absolute reliability they cannot be surpassed to-day, but for the reason pointed out by the author, [illegible] the plant. It depends almost [illegible] 15,000 kw. turbine that I have in mind, and find that the basis proposed by him, namely, 1 lb. per 1,000, as the total air leakage would be equal to 215 lb., or the amount of air leakage which would pass through a hole 5/16 in. in [illegible] fore appear to be quite high enough—in fact it would take [illegible] leakage. In a paper read last month before the Institu- [illegible] efficiency of the air-withdrawal plant and the state of the [illegible] working under the best conditions that a value of K of [illegible] working under low load it may be no higher than 300. [illegible]

In connection with cooling towers, I have compiled the following set of figures for insertion in the appendixes of [illegible]

[illegible]

	[illegible]	[illegible]	[illegible]
Gallons of water cooled per hour	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
Area of [illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
Gallons cooled per [illegible] hour	[illegible]	[illegible]	[illegible]

* G. G. STONEY. [illegible]

. Pearce.

Range of Cooling with Varying Inlet-water Temperature.

Atmospheric Temperature	Cooled by Forced Draught. Humidity			Cooled by Natural Chimney. Humidity			Cooling by Open-type Water Coolers. Humidity		
	60 %	75 %	90 %	60 %	75 %	90 %	60 %	75 %	90 %
40° F....	90–71	93–74	97–78	86–69	96–76	97–78	—	—	—
Drop	19	19	19	17	20	19	—	—	—
55° F....	103–83	106–87	96–78	—	—	—	—	—	95–75
Drop	20	19	18	—	—	—	—	—	20

for a constant inlet temperature. I have therefore chosen what appear to be the most reliable test results from the large number taken at various times, and give the actual figures of such test.

I think that anybody who has had experience with cooling towers will agree that it would be an improvement if they could be done away with. At the Stuart-street station at the present time we are dealing with a maximum demand of nearly 40,000 kw., which will be increased in the near future to 45,000 kw. The whole of this load is dealt with by means of cooling towers. In connection with our new Barton scheme I obtained some figures in regard to the cost of cooling towers as against an ample supply of canal or river water for condensing purposes, and I found that if cooling towers had to be installed it would cost, for a complete station of 100,000 kw., no less than £14,000 per annum in excess of that required by the alternative scheme. In connection with the date at which steam consumption tests should be made, the author's suggestion of six months on commercial load is I think excessive and would certainly not be accepted by the Manufacturers' Association. I think that a period of two months on commercial load might reasonably be allowed to elapse before the official tests are made.

. Wilson. Mr. D. Wilson: At the present time when everybody is striving after the last 1 or 2 per cent in efficiency it is well we should appreciate the margin on which we have to work, and the importance of obtaining correct and reliable information in regard to all the essential factors. In that respect this paper undoubtedly fills a gap, and whilst to many of us a few of the suggestions may seem commonplace and elementary, it is surprising how many tests are carried out without regard to the most elementary points. The number of variables that occur in boiler testing is exceedingly large, and it is only when such variables are fully appreciated and controlled that important results are really established. The margin for improvements in boiler working is becoming more and more narrow, and the contradictions which come before us from time to time are no doubt due to comparisons being influenced by these variables. Taking the question of the efficiency of boilers, some contractors' guarantees are creeping up to high figures. I am afraid that this is due more to competitive pressure than to scientific development, and it is probable that the contractor in stating an abnormal efficiency trusts that his plant will pass the test owing to the introduction of some of these variables. However, the author gives us a set of curves and tables which enable us to check these efficiencies, and I think Mr. Wilson
they should be kept carefully in mind as indicating what must be maintained in the way of final temperature and percentage of CO_2 in order to establish such results. A correct heat balance of course will prove whether a test is reasonable or unreasonable, and in this connection I am glad to see that the author adopts the generally accepted figure of 5 per cent for radiation and other unaccounted-for losses. Nobody has yet been able to measure correctly the radiation loss, and for anybody to balance the figures obtained from a test by suggesting that the combined loss is less than the figure given by the author is to my mind much the same thing as to draw upon an amount which we have mutually agreed to set aside as reserve. I also note that the author accepts the higher calorific value of the coal as a factor in the calculation; whilst contractors are prepared to give their guarantees on the "higher" or the "lower" value, it is a point which should be definitely settled. I believe that the Institution of Civil Engineers are about to issue a report embodying instructions for carrying out and standardizing boiler tests, in which they specify that the "lower" calorific value should be used. This is the value of the coal as fired, after making a deduction for moisture formed by the combustion of the hydrogen which has to be evaporated and superheated to the flue temperature, and if this correction is made in the calorific value it means that all efficiencies are automatically increased by a few per cent. There is naturally no actual saving in the coal bill as a result of this, but according to Mr. W. H. Booth's ideas it represents more correctly the true efficiency of the boiler, that is, the ratio of the heat actually absorbed by the heated surface to the heat "offered" to such heating surface. In any case this loss always exists and must have a place in the heat balance or in the calorific value if we are to appreciate fully the margin on which we have to improve boiler efficiencies still further. With regard to the evaporative capacities of boilers of various makes, we again have many contradictions. These also are probably due to the different variables not being appreciated and controlled. The evaporative capacity of any boiler must depend upon the grate area or the amount of coal which can be burned under the boiler, and a higher evaporative capacity cannot be accepted for any boiler unless we are prepared to admit that the efficiency of the one is higher than the other. On that point I welcome the author's effort to determine for us what is to be accepted as the true efficiency.

I think he will agree that he has not mentioned all the variables in connection with boiler testing. Probably the chief one is the coal itself. Those who have had experience of coal testing must realise how little is known even now about the physical properties of coal. Two samples of coal of the same approximate and ultimate analysis will behave quite differently in the furnace, and it is because of such variables that it is impossible to design a furnace or a mechanical stoker that will be ideal under all conditions. We must accept the one which offers the best combination of advantages. I quite agree with the author that an advance may be made by adopting a special design of stoker or furnace for handling very low grade and difficult coals, but I disagree with his somewhat limited reference to this question. The points covered by that reference can be overcome and have been overcome by many designs of mechanical stokers, including probably one of the oldest. As an instance I would mention two very large stations widely apart—probably the most efficient in the world—one is the Docksud station at Buenos Ayres and the other the Rosherville station of the Victoria Falls Power Company. At the former coal having a calorific value of [illegible] B.Th.U. per lb. is used, and the economical result of 25 B.Th.U. per watt-hour is being obtained. At the latter station the figure is 26 B.Th.U. and the fuel used contains [illegible] per cent of small coal, which again exceeds the margin given by the author as the limit. The calorific value of the coal never exceeds 10,500 B.Th.U., and under circumstances practically identical as regards design of plant and load both stations are doing equally well with two different classes of stokers, but in the reverse order to that suggested by the author—an interesting result for two stations so far apart and using such different coals. The design of mechanical stokers cannot be settled by the grade or calorific value of the coal alone; it is necessary to study its physical characteristics, and in this respect we have to learn a great deal more than we know at present. There again I am sorry to disagree with the author and with Mr. Pearce. The calorific value of the coal is no guide at all as to how a coal is going to affect the structure of the furnace or even the grates. I know of installations where coal of 14,500 B.Th.U. has been burnt for 10 years without any damage being done; on the other hand, I can give instances where coal of 11,000 B.Th.U. has caused very serious damage to the brickwork. The damage depends more upon the composition and fusing point of the ash in the coal, and the former is a point about which none of us know very much, whilst the latter depends to a certain extent upon the percentage of sulphur contained in the coal. There is a demand for a paper such as this, and there is a demand for a man such as the author to stand between the contractor and the customer. I welcome the author's effort to reduce to a more comparable basis these matters in which we are all so much interested, and I am certain that all contractors will support his endeavours.

Mr. J. FRITH: I take it that this paper is a plea for greater accuracy in the testing of power plant. I was disappointed in the first place in the author's treatment of the calorific value of the coal. Obviously that is the basis of the whole test, and the author seems to have forgotten to mention how it was taken. It would have been very interesting to have had his views on the correct method of ascertaining this value both in regard to the bomb [illegible] eter, as to whether to adopt the higher or lower heating value, and, if the higher value is used, whether the coal should be dried before being put into the calorimeter. If this were so, it would have been interesting to have a discussion on how to dry coal, because it is known that this is an exceedingly difficult process. Moisture as it exists in coal [illegible] it is therefore very difficult to dry coal without heating it sufficiently to drive off the volatile matter. In view of the author's [illegible] it is apparent that [illegible] 14.2 per cent [illegible] per cent [illegible]. Possibly it is the volatile matter [illegible] out, owing to its having been driven off in drying the coal; but of course this discrepancy makes it impossible to check any of the figures on the efficiency curves. I was also disappointed in the curves marked [illegible] and [illegible] efficiency." These [illegible] of the flue gases and the amount of CO, in order to ascertain the efficiency of the boiler. Somewhere in the paper the author mentions that this represents the maximum efficiency attainable, but I think it ought to have been stated more clearly on the curves. He has, it would seem, entirely omitted to take account of the CO. The curves cannot be checked because of these, to me, extraordinary analyses, but [illegible] in the water vapour and the flue gases, assuming there is no CO. Now the curves go down to as low as 25 per cent of excess air. To imagine that under these conditions there will be no CO is illusory, and when it is considered that 1 per cent of CO in the flue gases may mean a 5 per cent drop in efficiency it does not appear that these curves are valuable for the purpose which they are intended to serve. Then, again, I cannot see why the author uses a horizontal pipe in a flue to sample the flue gases. He must know that a great deal of stratification is to be found in the flue gases, and to collect the sample across a horizontal line seems to be fallacious; to collect vertically would have been an improvement, and the practice of using a cross tube is better still. It seems to me that in order to get an accuracy of 1 in 1,000 such considerations ought to be noticed. Broadly speaking, one would have expected far more discussion of the question whether to take in the power of the auxiliaries or not. Boiler makers will guarantee 10 lb. of steam per lb. of coal, and some will guarantee a kilowatt-hour per 10 lb. of steam; and yet it is a good station that can generate one kilowatt-hour on 3 lb. of coal. Much of that difference is due to the auxiliaries. In testing a boiler one ought also to take the fan into account. It is part of the working of the boiler, and the steam taken for it, or the equivalent of the steam taken for it, ought to be subtracted from the output of the boiler. It is more questionable whether one ought to take into account in the efficiency of the steam-raising plant the power for coal handling and ash handling. The same question arises with regard to the [illegible] pumps for the condenser, fans for the cooler, etc. All that would have been quite worth discussing. I do not quite see why the author has made the distinction between steel and wooden cooling towers. It seems to me that a better way would have been to deal with [illegible] cooling towers

Mr. Frith. with natural draught, and enclosed towers with natural or forced draught. We also have some figures for cooling towers which I have expressed in gallons per hour per square foot area for each foot of height and each degree Fahrenheit of cooling—they vary for open-type towers from 66 to 83, and for closed towers go up to 204 gallons per hour.

Mr. Seaton. MR. G. D. SEATON: I sympathize with those who think that an acceptance test should be conducted by an engineer independent of both the contractor and the customer, but I entirely disagree with the author's suggestion that the test should be made after the machine has been in use six months. In my opinion the test ought to be made as soon as possible. However, in advocating independent tests serious difficulties at once arise. The first is that the cost of an independent test would probably be at least something like £100; but it is evident from what the author says on page 109 that a little money spent on testing is a very good investment. There is another more serious difficulty. Many engineers consider it a reflection on their technical knowledge to call in an expert to make the tests, but I maintain that every engineer should confine his attention to the work that he is accustomed to, and in my opinion the average engineer, though he may know his particular business perfectly, cannot find time to devote to the study of the special features that arise in connection with testing. I am totally opposed to tests at the makers' works. There is considerable trouble with turbines in this country at the present time, but there is no need to be pessimistic. The trouble, I am glad to say, is entirely confined to turbines of the cheap type, and I hope that out of evil will come good; engineers will begin to see that if they want to avoid trouble and get good results they must install well-made plant.

Mr. Peck. MR. J. S. PECK: Mr. Seaton spoke in favour of calling in outside experts for taking tests where large sums of money may be involved in the results obtained, and I wish to associate myself with him. All designers of machinery know how essential it is to obtain accurate results from the testing department, for upon the results of these tests future designs are based, but while we may have accurate data of our own machines we know very little about the actual performances of those of our competitors, and we are apt to question the accuracy of published figures showing abnormally good results. I believe that the publication of actual test results obtained by impartial observers would result in increased progress, for if we knew that our competitors were excelling us we should strain every nerve to equal and surpass them, and thus the whole industry would benefit. I myself should welcome the introduction of the custom of employing independent experts for all tests where the question of a penalty or bonus is involved. The only restriction that I would urge is that the testing expert should be one in fact as well as in title.

Mr. Watson. MR. S. J. WATSON: There are one or two matters which I should like to mention. Mr. Pearce has referred to them, but I wish to supplement his remarks. The first is with regard to obsolescence. As the author points out, this has not been dealt with in the past as it ought to have been. There is no doubt that the small plant installed 10 or 15 years ago is to-day quite out of date, and if proper attention had been paid to the financial side of electricity supply such plant would have been eliminated from the capital account and more modern plant substituted for it. Most members probably know that 15 years ago, for instance, the cost per kilowatt of a generating set was £10 to £15, and the steam consumption was anything from 30 to 40 lb. per kw.-hour. To-day large modern turbine plant can be bought for about £3 5s. per kilowatt and the steam consumption is between $11\frac{1}{2}$ to 13 lb. per kw.-hour. Bearing in mind the cheapening of the plant and the reduced steam consumption there is not the slightest doubt that the early plant should be entirely written off. On page 109 the author says that plant rated at less than 5,000 kw. in the case of turbo-alternators, or 30,000 lb. per hour for steam boilers, should be written off in 8 to 10 years. I do not understand why he should fix on a definite size of plant and a definite period; it seems to me that obsolescence is more a question of what is the percentage size of a given set to the total plant installed, and also of its economical usefulness under the then existing working conditions. The sets which many of us have got rid of were rated at 250 or 300 kw. or less, and at the present time much larger plant—2,000, 3,000, or 5,000 kw. sets—are being installed. If very large stations are eventually erected it may easily happen that it will pay in the future to write off the 5,000 kw. set now being installed just as it has been advisable to write off the 200 kw. or 300 kw. sets which were put in 10 or 15 years ago. Another point on page 109 is the question of load factor. I fail to understand what the author means where he says, "Further improvements which will subsequently be obtained when the load factor is 50 per cent will not be a vital matter in the cost of generating electrical energy." I hope that he will state clearly what is here meant. The only way in which I can apply the above remarks is, that when the load factor was only about 12 per cent we incurred certain costs per unit, and when it increased to 25 or 30 per cent, as is the usual practice to-day, there was a very large percentage saving, but that there will not be so large a percentage saving when the load factor increases from 30 per cent to 50 per cent. That, of course, would be quite true, but I do not know whether he intends to convey that meaning. In any case there is no doubt whatever that a marked reduction occurs in the working expenses and in the capital cost per unit sold with an increase from 30 per cent to 50 per cent in the load factor. Further on he discusses 7,500 and 10,000 kw. sets and shows how much extra can be paid for a given percentage saving in the steam consumption. That seems to me a somewhat difficult matter to deal with. My own view is that all makers of prime-movers should endeavour to obtain the best results that they can from their plant, and if a saving of 10 per cent in the steam consumption means an additional cost even of £2,000 or £3,000, the manufacturer should still standardize such plant. A further point arises: How much extra is one justified in paying for a given reduction of steam consumption? It may be the case—I think it would be—that on a set of the size mentioned one would willingly pay £2,000 or £3,000 extra, but would we be prepared to give £10,000 extra, although the author shows that it is worth £24,000 more? I believe that nobody would be prepared to do so? Why? Because one is not certain that the guaranteed results would be obtained; and in any case such guarantee only extends

[illegible] as a check against the recording instrument. In that [illegible] the valve reversed to the Orsat apparatus. A few strokes of the blower was quite enough to ensure that a fresh sample was obtained from the flue, the test was completed in a moment or two, and the condition of the fire was compared with the result. Slight adjustments of the fire [illegible] The author refers to the reduction in the amount of CO, which very often occurs between the outlet of the boiler [illegible] through an economizer. I think it is generally known that much of that reduction, though not the whole of it, is due to air leakages through the scraper chain holes of the econo- [illegible] is being emptied. By that means—in fact, I think, by [illegible] tests has also been mentioned. It seems to me that the author is absolutely wrong in saying that efficiency [illegible] the efficiency of the alternator (which nearly always runs with a power factor less than unity)—the test should be taken at the power factor for which the alternator is designed and under the actual operating conditions. With [illegible] type even with plants of fairly large size. In the first [illegible] whatever the [illegible] erosion or corrosion on the blading and the blades are [illegible] the same as when the machines were first installed.

Mr. W. [illegible] mentioned by Mr. Frith which [illegible] word "Orsat" used to define the mea[illegible] Is not the curve accurate whatever method be adopted for [illegible] plotted simply from the ordinary Bunte formula, whilst [illegible] just where the mod[illegible]

Mr. Cramp. obsolescence will occur in regard to size, and it must be allowed for, but it will not arise—at any rate not to the same extent—in connection with the type of plant. I find the paper also a little disappointing in its scope. Its title is "Power Plant Testing," whereas it is really a series of notes on the testing of a very special type of power plant. The author has already said that he does not include gas and oil engines. That is a large deduction to begin with; but if the paper be examined it is found that only steam-turbine generators are considered. There is no mention of reciprocating engines, nor is there any discussion of plants of which the output cannot be measured electrically. Now in ordinary practice for one plant driving an electrical generator there will be ten without an electrical generator, and certainly there will be a very large percentage which are not concerned with turbines. In consequence, much of the paper is not ordinarily applicable. Moreover, not only is the paper confined to a particular type of steam engine; it is also confined to a particular type of boiler, to a particular type of condenser, and apparently also to a particular type of grate and stoker. For instance, all the difficulties in testing which arise on account of the use of Lancashire boilers, sprinkler, coking, or shovel stokers, jet condensers, and various types of grate are disregarded by the author. These considerations also affect the matter of accuracy. For, after all, accuracy in steam-plant testing depends upon the fact that the condition of the fire at the end of the test must be similar to that at the beginning; yet no hint is given as to how the fire depth is to be measured nor as to how we are to ascertain its condition. I submit that with the ordinary methods of regulating the fire it is quite impossible to reach a degree of accuracy such as the author suggests. With regard to testing on unity power factor, it seems to me exceedingly easy to build a machine to give good results on unity power factor and disappointing results on, say, an 80 per cent power factor; so that the latter test is of great importance as determining the value of the machinery supplied, especially where close regulation is required. On page 114 in the second column, just before "Condensers and Air Pumps," there is a paragraph which I should like the author to explain. In connection with air pumps he refers to tests of the quantity of air measured by the indraught through calibrated nozzles. I should like to see some of those nozzles or a description of them. My impression of nozzles is that they are extremely inaccurate. With regard to the question of fans, I should like to know where the author measures the pressure and in what way he calculates the efficiency. He says that a set of home-made wooden nozzles can be fitted in turn on the outlet of the fan. In my opinion such a method is likely merely to repeat the errors that have been common hitherto in ascertaining the efficiency of the fan. In any case, fan-testing through a calibrated nozzle wherein the pressure is measured close to the point where the air-path is reduced in section is practically useless, the pressure reading being altogether unreliable. One must also remember that the ordinary pressure gauge used by engineers for testing fans is a water gauge graduated perhaps in very small divisions. Usually, however, the total pressure is only equivalent to about 4 or 5 in., and since it cannot be read to a greater accuracy than, say, 1/16 in., the error in efficiency is likely to be very large. Much more delicate instruments are required, and, as a matter of fact, are to be had for this purpose. The testing of fans has reached a stage when it may be scientifically carried out. I quite agree with the author that corrections should be avoided if possible, but in nine cases out of ten it is impossible to reproduce the exact conditions laid down in the specification. At least that is my experience. A serious mistake occurs in the author's argument concerning the great importance of steam consumption. He says that £375 per annum capitalized on the basis of 8-years' life is £3,000. Either this sum is incorrect, or else unusual values have been taken for interest and sinking fund—£2,000 is much nearer to the ordinary capitalized value of £375 on a basis of 8 years. In conclusion, I should like the author to give us the data upon which other statements are based. For instance, on page 111 in regard to the loss by radiation he says that 3 per cent in a 20,000 lb. boiler well lagged is, in his opinion, a sufficient allowance, but he does not give us any figures to support that information, nor any indication as to how he has arrived at his conclusion. On page 114 also with regard to the mercury column for peripatetic testing, he says that he finds it necessary to manufacture his own, but he does not give us any details. I hope that in his reply he will give further information on these matters.

Mr. McKinnon. Mr. E. C. McKinnon (*communicated*): With such an attractive title I anticipated a more comprehensive paper on this subject, and I could not but feel at the end that the title was a misnomer. I should have expected and welcomed some remarks on the testing of storage batteries, which are more and more becoming a recognized auxiliary to power plant, and yet the omission is significant of apparent indifference to this important branch. I find—not invariably but very commonly—a vagueness about specifications issued by central-station engineers and consulting engineers when dealing with storage-battery tests which is in such marked distinction to the explicitness of the tests to be carried out on other sections of the power plant that I am tempted to press for an explanation. A bonus clause is never embodied in the specification of a storage battery. Does the engineer deem it sufficient to specify the required capacity and protect himself by a maintenance agreement to ensure that this will nominally be maintained for a term of years? The battery tests on site usually specified are neither convincing nor useful. It is quite a simple matter to form or over-form plates to give their initial rated output, assuming that this has been stated on a conservative basis. The user is not necessarily a loser if he receives plates which might at first be rather low in capacity, for this may mean that the lead base has been attacked or formed to a comparatively small degree, and the life of the plates will thereby tend to be increased. What does a test on a new battery as at present taken convey to engineers? Simply that on a said date under certain conditions the battery is found to have a certain output. It does not prove that the plates are well designed, have been made from pure metals, are free from dross or imperfections, that all traces of forming reagents have been removed, that the plates will have a normal life, or that they will maintain the output obtained. What, moreover, is the test? A study of specifications issued during the past few years will show that generally this is "Having

[illegible]

each set or unit of plant. This curve should be plotted to show the hourly cost of coal from zero to full load, and I suggest that it be set out in conjunction with the constant [illegible] set for any particular load. In studying this que[illegible] [illegible] steam consumption. The second set should be purchased with low running costs kept well in view. To illustrate what I mean I have plotted a diagram (Fig. C) which

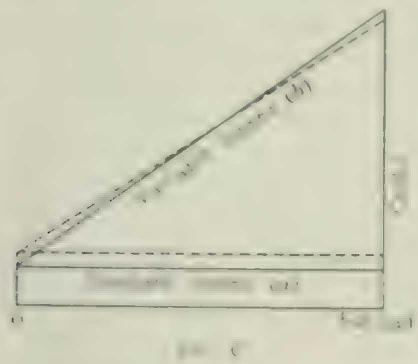


Fig. C

relates to two sets of equal size but of different design, one having low capital costs and the other low running costs. It will be seen at once from this diagram that the greatest [illegible]

[illegible] wooden prop, which at the right moment was pulled [illegible]

[illegible] taken any further facts into consid[illegible] [illegible] period, for they are not [illegible] conditions. To meet such conditions I [illegible] the most satisfactory test is obtained by [illegible] under [illegible]

[illegible]

Mr. Schuster.

wherever practicable I prefer to test each sample of coal for at least three days and nights and if possible a full week under such conditions, the boilers and tanks being shut off simultaneously at similar times each day thus enabling the test to be subdivided at will, the coal used for banking the boilers being duly noted. This system has been adopted as the result of several hundred tests on various factory plants. If the coal be so variable in quality that the gases vary from 8 per cent to 14 per cent irrespective of the conditions of the fire, as is to be inferred from the author's statement, I consider 10 tons of coal insufficient, even if burnt in one boiler, to make a proper test of the average quality of the fuel for the purpose of placing a contract for a bulk supply, especially if the coals when compared give nearly similar results. Among the reasons why I consider coal should be burnt on test under actual working conditions and in the same number of boilers as is used regularly, is the fact that the temperature of the gases leaving the boilers varies according to the quality of the coal, and in practice such a test therefore should comprise not only boilers but economizers. This source of error is often not taken into consideration in making tests on a boiler which is only one of many serving an economizer. On whatever lines the test be made it must clearly be made over a sufficient period to ensure the results being accurate and the coal used being of average quality; the consumption must also depend on the size of the test boiler or boilers. Most important of all is that the coal should be burnt at as nearly the same rate per square foot of grate area as in everyday use. For these reasons it would have been preferable if the author had suggested a time and not a weight basis, if any standard be desired. On page 114 he states that he has never seen a really satisfactory portable mercury column, and he recommends the use of an open-type column, plus an aneroid barometer for condenser tests. I would suggest that provided proper precautions are taken to prevent rushes and slow creeping of moisture an "absolute" mercury column is far preferable, since it gives one absolute reading and therefore ensures accuracy. I have in fact such an instrument in daily use which was made to my design, with a U-tube and sliding scale, thus dispensing with all inaccuracies of calibration. This is most convenient for carrying about and has always given very satisfactory results; the cost was only 50s. complete in its case. It is of course fitted with cocks to prevent the mercury hammering in the tubes. When carried it can be swung freely without risk of damage or of air getting into the tube. The instrument is very useful as a standard vacuum gauge for calibrating purposes, and is also of use as an ordinary barometer. I am interested in the author's suggestion on page 114 with regard to the setting up of a standard for what might be called the "incapacity" of an air pump. Many papers read recently on condensing plants give estimates of the quantity of air to be dealt with by air pumps, but they always seem to omit to state their authors' ideas on a far more important point, namely, the capacity of the air pump required to deal with this air, a factor which must be decided by the partial air pressure in the condensers. The author suggests that this figure should be 0·3 in., which appears to conform with common practice. It is worthy of note that this figure increases the steam consumption of a turbine 2 per cent for a 28/29 in. vacuum if not compensated for by extra tube surface in the condenser, and the question arises whether this figure is not too high. At any rate I trust the discussion will elucidate what is the lowest value that designers consider the partial air pressure should be reduced to in order that the extra value of the running and fixed charges on the necessary extra plant do not exceed the saving. On page 116 I note that the author advocates the measurement of the quantity of circulating water by means of its temperature rise, and states that this method "allows of considerable accuracy." I have often adopted this method myself, but on theoretical grounds alone have always considered the results to be only approximate. Even if condensation in exhaust, condenser, and prime-mover due to radiation and conduction be neglected, it can be easily calculated that steam initially at 180 lb. pressure and superheated by 150° F. when expanded adiabatically to a $28\frac{1}{2}$ in. vacuum has a dryness fraction of only 79 per cent, or if it be only saturated initially of 75 per cent. This cause alone would make the quantity of water calculated according to the method advocated by the author theoretically $26\frac{1}{2}$ per cent and $33\frac{1}{3}$ per cent respectively more than the actual. Now although in practice I believe this difference does not reach these figures, it seems clear that this method of measuring water though extremely simple and convenient cannot be considered as giving any high degree of accuracy, as suggested, unless suitably corrected on some sound basis.

Mr. Jepson.

Mr. A. E. JEPSON (*communicated*): With regard to the author's statement that stray fields affect watt-hour meters, he has omitted to mention that the Aron clock-type meter is an exception, as has been demonstrated both in theory and in practice. The proposal to place the instrument at a considerable distance from the shunt so that it is not in proximity to stray fields, has the objection that the true temperature correction cannot be ascertained. The author proposes to fix a thermometer in the case of the instrument, but as the leads often represent one-third of the total resistance (including that of the meter) a false correction for temperature can easily be made. It is not unusual to find a difference in temperature of at least 30° F. between the positions where the meter and shunt are fixed. By using a total-current type of clock meter the temperature coefficient can be reduced to half the figure of 0·03 per cent per degree F. mentioned by the author. In view of the instructions given as to the careful handling and setting up of the meters used on a particular test, I am sure those engineers who use for their large power circuits two or three meters in series and who get a maximum difference of 2 per cent will feel themselves particularly fortunate. It is to be regretted that more care is not taken with test meters as well as with ordinary meters. I do not agree with the author's statement that tests with 3-phase meters can be made with an accuracy of 1 in 1,000. A change in temperature of 2° F. would account for quite this error, and as it usually takes at least four days before the interior of a meter assumes a steady temperature, I consider 0·1 per cent an impossible figure, particularly when one remembers that the electricity supply in the test room is unlikely to have the same wave-form as that on the distribution system. As temperature also affects the power-factor

[illegible] total cost per unit, because the improvement between [illegible] with the costs due to high-tension distribution, transformation, low-tension distribution, and, above all, services, [illegible]

On the question of testing at unity power factor, I have [illegible] what I mean it would be necessary to state actual figures. We have measured the losses due to a decrease of the power factor in the case of a large set, and it was found that if these losses were estimated instead of measured the errors thereby introduced are not large compared with the errors that may occur if meters are used at low power factors. The only published figures to which I can refer on this point are, I think, some given by Messrs. Escher, Wyss & [illegible] consumption at 0·6 power factor as compared with unity power factor. Nobody would expect an alternator efficiency of much over 95 per cent. As at least 2 out of the remaining 5 per cent is due to what we may call extraneous causes, 3 per cent is left for iron and copper losses. If to that 3 per cent has to be added considerable losses due to [illegible] hot. My whole point is, of course, that it is better to quote the steam consumptions in the contract on a common basis of unity power factor.

I would also point out that in the paper I have credited to the larger undertakings a clear knowledge of the trend of events which is shaping present-day policy.

The reasons which Mr. Pearce and Mr. Watson have in mind are supplementary rather than contradictory to those [illegible]

[illegible] bonus.

[illegible] agree to these measurements. The question of condenser losses was widely dealt with in Mr. Seanes' paper before the South Wales Institute of Engineers,* and the discussion thereon.

Mr. Pearce's remarks about continuous-current instruments and shunts largely co[illegible] of my remarks in regard [illegible] 3-phase meters. These were based on the experience of many cases. Any question of absolute accuracy belongs to the standardizing institution.

With reference to air leakage, Mr. Pearce agrees that [illegible] the condenser for air co[illegible] the value of K, I dealt with this in my rep[illegible] We are indebted to Mr. Pearce for the pub[illegible] relating to cooling towers, and on that subject my meaning might be made clearer. It is granted that nobody would [illegible] inland centres with water for domestic and manufa[illegible] purposes. The addition of a large electric supply makes [illegible] tendency towards using the sewage effluent for condensing

[illegible]

Mr. Selvey. purposes, that is, of using the water brought into the district over again. The amount available is about 35 gallons per head per day. With our big stations we may use say 20 lb. of steam per unit sold. A good sales figure for the present time is 1/3 unit per head of population per day. Hence if the circulating water amounts to 70 times the feed water, the water required is now 46 gallons per head per day, which will use up all the sewage effluent and more. Figures published* show that if the "all-electric" era comes to pass we may use as much as three units per head per day, or nine times as much. The sewage effluent will then give a considerable margin over the make-up water required for the cooling towers. Hence the suggestion that engineers will pay more and more attention to this apparatus.

I should have liked to have said something more in the paper on the subject of cooling towers. I was asked why I made a difference between steel and wood. It is because I think the arrangements are so different that they must be expected to give different results. I have no personal experience with steel towers, but from figures handed to me it would seem that greater cooling takes place with the steel tower for the same loading. At the same time there are other questions such as upkeep which make the whole a commercial question and not merely one of efficiency.

Mr. Wilson's remarks deal with the question of the higher and lower calorific values of coal. In fixing a standard the difficulty often arises: are we to have a physical standard or are we to have something connected with the apparatus? Turbine designers have got over the difficulty very neatly by adopting two terms, "efficiency" and "efficiency ratio." When they want to produce a psychological effect upon the buyer by showing a big figure, they always quote the efficiency ratio. The efficiency of turbines on what is known as the thermodynamic scale (always used for gas engines) at a very high limit may yet approach 30 per cent. Referring to the efficiency ratio, we now hear of figures nearly up to 80 per cent. For my own part I suggest that the standard ought to represent physical facts and have no relation whatever to the apparatus. The efficiency ratio has its place very properly in the theoretical analysis of the results, where it is of great value.

Mr. Wilson also referred to the nature of coal; it is impossible, however, in one paper to discuss in detail the various subjects touched upon. There is a comprehensive book † on the nature of coal which still fails to explain "all the facts." I must be content therefore with the judgment passed on my few inadequate remarks on the efficiency of boilers. It is often the bituminous coal which gives trouble, and in this connection I agree that efficiency does not always depend upon the calorific value but is also dependent upon the nature of the coal.

In reply to the criticisms of Mr. Frith and Mr. Cramp, the curves represent, of course, the limits above which efficiencies should not be expected. It was not my intention to suggest that there was accuracy to the limit of 1 per cent, but that it should be an ideal to be aimed at. An ideal attained ceases to be an ideal. It was only in connection with turbine testing that that figure was mentioned. I should not like even to lay down a margin for boiler testing. My object was to give some figures which members may refer to in order to appreciate the conditions necessary to obtain the high figures which are sometimes put forward. Mr. Selvey

* W. A. GILLOTT. Electric cooking and heating in private houses. *Journal I.E.E.*, vol. 53, p. 42, 1915.
† V. B. LEWES. "The carbonization of coal."

Mr. Seaton's and Mr. Peck's remarks were very much to the point. It is good to hear that there are firms in this country who will be glad to have their plant tested in such a way that the result may be brought home to all concerned.

In part answer to Mr. Watson's remarks, the question of obsolescence I anticipated would raise discussion, and it is evident that everybody is not so confident as I am of the great future before electricity supply. I think it will not be many years before a 5,000 kw. set will be considered to be quite small. To-day the Detroit Company are using boilers of 100,000 lb. per hour duty, and there are also some of these boilers in London. A 35,000 kw. turbo-alternator is also being built.

As to the question of high draught, I do not say it is necessary in order to obtain a high efficiency, but I can see tendencies which may force it upon us. I am not advocating it here, but I think it will come. There will always be times even in a station which has a 50 per cent load factor when the engineers will be at some trouble to maintain the normal steam pressure, and it will be for those emergencies that the high draught will be utilized. The tendency is all towards being able quickly to rush a boiler up to full steam.

Mr. Watson commented on how I took the CO_2 sample, and Mr. Frith criticized the diagram. It is not intended to be a working drawing; it is only suggested that a sample should not be taken at a single point.

As regards the question of nozzles for fans, again one has to draw a broad line between what can be done and what is done, and that is what is hinted at in the paper. The question belongs to the domain of works testing.

It has been suggested that I have dealt with only one type of boiler. There is some justification for that. A lot of good engineering is being done in power stations and it is gradually leading to a more or less standard scheme. It is that which I had in mind—the large water-tube boiler with the chain-grate stoker; it did not occur to me to mention other types of boilers when writing the paper, which only relates to steam-driven power stations. I think that Lancashire boilers would not now be installed in a new power station.

The nozzles for testing air pumps are, I believe, due to Professor Leblanc. They can be made with reasonable accuracy and are not at all difficult to calibrate. Very high accuracy is not so necessary when trying to get the capacity of an air pump. The paper clearly states that these very careful measurements are proposed in connection with the penalty and bonus clauses, which, of course, so far apply only to steam turbines.

In reply to the other points raised by Mr. Cramp and Mr. Frith, "CO_2 by Orsat" signifies the percentage of CO_2 in the gases when the steam therein has been condensed, which is of course different from the actual percentage in the flue. Mr. Wilson answered Mr. Cramp's query as to the reason for including "elementary" knowledge. The variation in turbine efficiency from start to finish is greater than that caused by the step from reciprocating to rotary machinery, as is also the variation in maximum size and capital cost which is at present rapidly

[illegible]

In reply to Mr. McKinnon, I should not like it to remain [illegible] matter had to be limited to steam-driven power stations. As these are fast becoming all high-tension, 3-phase, the question of the battery belongs more properly to transformation and distribution than to generation. The [illegible] Mr. Chattock has said about the need of ventilating the whole subject of power-plant testing.

[illegible] life for a present-day turbo-alternator. It did not of course mean that its life would come to a sudden end in eight years, but that towards the end of that time it would become peak-load plant, the efficiency of which would [illegible] load (making 75 per cent load the most economical point) the consumption is practically constant. By the 100 per cent load is meant the maximum continuous rating. The amount of air carried into the boilers depends on the plant between the air pump and the feed pump, but in any case it is not a very large proportion of the total air leakage [illegible] advisable to keep it as low as possible for other reasons. His remarks on short-circuit tests are of considerable interest.

In reply to Mr. Schuster, the atmospheric temperature of 60° F. and the "higher" calorific value have been used for Figs. 1 to 3. Regarding the method of testing coal which [illegible] cases to which he refers, but it calls for a different kind of [illegible] the aneroid, the barometer sta[illegible] acceptance test. In respect to the remarks made on the heat per lb. of steam going into the cond[illegible] 2 per cent, and since space would not permit of going fully into the subject I propose to leave it at that.

In reply to Mr. Jepson I am aware of the [illegible] points of the Aron meter, but, from what was [illegible] discussion at the Newcastle meeting, the [illegible] question of lea[illegible] correction to be kept at a [illegible]

SWITCH AND TRANSFORMER OILS.

Introductory.

As the result of discussion by the Research Committee of representations made to it in regard to the necessity for research into certain properties of switch and transformer oils, and also in regard to the desirability of standardizing the tests on these oils, a Sub-committee has been appointed to formulate a scheme for dealing with these questions.

At its first meeting, held on 8 July, 1913, it was decided to issue circular letters to a number of manufacturing firms and colleges asking for their co-operation in the aims of the research. The replies included a large amount of hitherto unpublished matter, and, with the answers and comments upon an amended set of questions (published in the *Journal*, vol. 52, p. 48, 1914, and reprinted here for convenience of reference), have been considered to be of such value that their dissemination as an interim report would be not only of wide interest, but also of assistance to those who have promised further co-operation. It will, it is hoped, stimulate those who have had occasion to consider this subject to assist by supplying information and to co-operate in the research.

The Sub-committee has therefore invited Mr. W. Pollard Digby to prepare the following report, in which the replies have been grouped as far as possible under the headings indicated in the list of questions referred to above.

The remarks of individual contributors are to a large extent identified by the name of each, because it is felt that the fullest personal recognition is desirable of information supplied. Names are also given because in some cases different contributors are not in agreement, and in other cases because Mr. Digby considers that the industry as a whole is not yet prepared to accept as final some of the replies given to certain questions.

QUESTIONS.

Insulating Oils.

Section A.—Chemical.

1. In any given transformer oil what is the relation between temperature and tendency to sludge formation in any oil exposed to the atmosphere?
2. Under abnormal conditions of specially high temperature in the laboratory what, for any given temperature, is the time required for the manifestation of sludge?
3. What laboratory tests can be devised to determine the amount of sludge produced under abnormal conditions of specially high temperature?
4. Whether the tendency to form sludge occasioned by high temperature and dry air or oxygen at one point can be neutralized by artificial cooling at another at any defined working temperatures?
5. Whether the tendency to form sludge can be neutralized by keeping the surface of the oil in contact with an inert gas such as nitrogen or carbon dioxide?

Physical.

6. Under normal working conditions what period elapses before the tendency to sludge formation is manifested in high-tension transformers?
7. What changes in viscosity, specific gravity, flash-point, relative thermal transference, dielectric strength, and specific resistance, accompany the formation of sludge?
8. How are the electrical properties of the oils and the formation of sludge affected by the circulation of air over their surfaces?
9. What is the temperature to which different oils can be raised repeatedly without appreciable change in their physical properties?

Chemical and Physical.

10. How do oils of different specific gravities and viscosities compare as to their liability to form sludge at temperatures of, say, 60, 70, 75, 80, 85, and 90 per cent of their initial flash-point?

Section B.—Chemical.

11. What is the amount of moisture which can be absorbed from the atmosphere by a dry oil at various temperatures, and how should such increment of moisture be determined?
12. What chemical or physical standard should be laid down as constituting a dry oil, and what changes in specific resistance and dielectric strength accompany increments in moisture?

Section C.—Chemical.

13. Did the usually accepted tests for the detection of acid, alkali, sulphur, resin, or resinoid materials lead to comparable results?

Physical.

14. In determining dielectric strength and insulation resistance what apparatus should be employed, how are different methods comparable, and what standard conditions, such as shape of electrodes, intervening distance, depth of immersion, movement, if any, of oil, etc., should be adopted?

Section D.—Physical.

15. Whether any practical means are in vogue for the laboratory estimation of the relative thermal transference in switch and transformer oils, what standard apparatus should be employed for such a purpose, and by what means should this property be expressed?
16. Is it at present possible to express the relative thermal transference of any oil at, say, 50°, 60°, 65°, 70°, and 75° C. as a function of its specific gravity and viscosity at these temperatures?

Section E.—Chemical.

17. What is the chemical composition of the gases (known to be highly explosive) which are liberated by an arc, and does their composition vary with different mineral oils?

Chemical and Physical.

18. Whether, and if so to what extent, the amount of carbon produced by an arc under any given oil varies with the temperature of that oil, or whether the temperature being kept constant, the amount of carbon produced varies with the specific gravity or viscosity of the oil, and if so, to what extent?

[illegible]

REPORT ON SWITCH AND TRANSFORMER OILS.

By W. [illegible], Associate Member.

[illegible]

[illegible]

TABLE A

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	0·88	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	[illegible]	[illegible]	20,000	Light amber
4a	[illegible]	[illegible]	354	[illegible]	Light amber
5	0·885	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	[illegible]	[illegible]	[illegible]	12,500	[illegible]
9	[illegible]	1,133	[illegible]	[illegible]	[illegible]
10	0·92	[illegible]	[illegible]	[illegible]	Amber
11	[illegible]	[illegible]	[illegible]	14,300	Light amber
12	[illegible]	[illegible]	[illegible]	14,000	Orange
13	[illegible]	[illegible]	[illegible]	14,300	White
14	[illegible]	135	345	7,000	Claret
15	0·91	[illegible]	[illegible]	14,000	Light amber
16	0·91	[illegible]	[illegible]	12,000	Amber
17	[illegible]	[illegible]	[illegible]	13,400	White
18	[illegible]	142	[illegible]	[illegible]	[illegible]

now before the manufacturers and users of oil for insulating purposes." This subject has also been exhaustively treated in Dr. Michie's paper † read before the Institution [illegible]

Messrs. Ferranti, Ltd., have estimated the comparative liability of oils to form sludge by a "short duration" test [illegible]

[illegible] be tested are placed in a long-necked flask of 500 cubic cm. capacity. The neck of the flask is closed by a stopper carrying two glass tubes, one of which reaches to the bottom of the flask and the other is short and connected with a suction pump working at the rate of two strokes per second. By this means ozone is drawn through the oil. The flask is kept at a constant temperature of 280° F.

[illegible]

TABLE B

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	[illegible]	205	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	157	[illegible]	[illegible]	[illegible]
5	[illegible]	203	347	[illegible]	[illegible]
6	[illegible]	[illegible]	334	[illegible]	Orange
7	0·94	[illegible]	[illegible]	[illegible]	[illegible]
8	[illegible]	70	[illegible]	[illegible]	[illegible]
9	[illegible]	over 2,000	[illegible]	19,500	[illegible]
10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
11	[illegible]	147	[illegible]	11,000	[illegible]
12	[illegible]	[illegible]	335	[illegible]	[illegible]
13	[illegible]	[illegible]	[illegible]	12,700	[illegible]
14	[illegible]	270	[illegible]	10,200	[illegible]
15	0·94	[illegible]	[illegible]	14,400	[illegible]
16	[illegible]	334	[illegible]	[illegible]	[illegible]
17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TABLE C

[illegible]

[illegible]	[illegible]
1	[illegible]
2	11
3	[illegible]
4	[illegible]
5	[illegible]
6	[illegible]
7	[illegible]
8	[illegible]
9	[illegible]
10	11
11	5
12	[illegible]
13	[illegible]
14	4·5
15	[illegible]
16	[illegible]
17	[illegible]

The following are chemical analyses of oil similar to No. 4 and of sludge formed by oil similar to No. 1 :—

Oil similar to No. 4.

Saponifiable oil and resin ...	Absent
Free fat acid neutral reaction ...	0·005 per cent
Mineral matter and metallic salts	Absent
Suspended matter	Absent

This oil conformed with the usual chemical characteristics of a mineral transformer oil.

Sludge from oil similar to No. 1.—This analysis proved to be tedious on account of the difficulty in obtaining clear filtration under treatment with various solvents. In order to diminish undue solubility of the sludge in the oil present and in the solvent for the removal of the latter, the sludge was freed from oil as far as possible by drying it on a porous plate out of contact with air, and then submitting it to examination, the results of which are as follows :—

	As received	Oil-free Sludge
Oil	88·725	—
Organic acids soluble in petroleum spirit	0·260	2·31
Organic acids soluble in ether—		
(1) Free	0·853	7·56
(2) Combined	2·362	20·96
Neutral unsaponifiable solid—		
(1) Soluble in ether ...	4·787	42·46
(2) Soluble in benzol ...	1·296	11·50
Insoluble in benzol (carbon)	0·373	3·31
Basic solid soluble in ether	1·183	10·51
Copper oxide	0·060	0·53
Ferric oxide	0·007	0·06
Other mineral matter ...	0·088	0·78
	99·994	99·98

Further examination of the fractions elicited the following information :—

Organic acids soluble in ether.—The molecular weight of the mixture of these was found to be 291, and they proved to be saturated acids of the paraffin series formed of brown needle-shaped crystals.

Neutral unsaponifiable solids.—These were dark brown, brittle, scaly powders, the soluble part being the darker, and both being derivatives of the paraffin series. The basic solid was light brown in colour, translucent, and non-crystalline, and consisted of bases of the paraffin series.

In the opinion of Messrs. Ferranti, all the products found are the result of oxidization, with the formation of complex organic acids, dehydrogenated hydrocarbons, and oxidized resinous asphaltones of the mineral oil originally used; whether the copper and iron are present as oxides, or partly as metal and partly as oxides, Messrs. Ferranti are unable to say definitely, but they do state that part of the copper was present as organic acid compounds and that traces were in the metallic state.

With reference to these instructive figures and comments, the author notes that the volume of ozone employed is not stated. The correlation of these figures with those obtained by Dr. Michie's method is therefore very difficult. The method employed by Messrs. Ferranti is undoubtedly one available for rapid works tests of a comparative nature. It must, however, be remembered that although the oils described had initial flash-points varying from 278° F. to 400° F., they were all tested at a common temperature of 280° F. without reference to this variation. The relation of test temperature to flash-point is of considerable practical importance. In Dr. Michie's tests the temperature was 150° C. (302° F.); whereas Messrs. Ferranti use 280° F. It is desirable that similar experiments should be made on a series of oils in which the test temperature is varied as in Question 10, when the time and the air (or ozone) volume remain constant.

The Victoria Falls & Transvaal Power Company define as follows what they understand by "transformer oil" and "sludging" :—

"We assume in these questions and in the answers to them that a transformer oil is a pure hydrocarbon oil, free from any animal or vegetable oil (such as the so-called 'fixed' oils consisting of compounds of fatty acids with glycerol or with other alcohols of high molecular weight), free also from additions of any substance (such as resin, soap, etc.), which would modify its composition and properties, and that it is in a more or less refined state, *i.e.* it may or may not contain impurities indigenous to the crude oil which may or may not affect its properties as a transformer oil.

"We mean by 'sludging' the thickening of the oil itself or the formation of deposits by alterations in the chemical constitution of the oil, and not mechanical sludging caused by dust, either dry or wet, permeating the oil from the atmosphere, neither do we mean thickening of the oil caused by the solution of insulating varnishes or cements used in the construction of the transformer."

The Victoria Falls & Transvaal Power Company then proceed to discuss Questions 1 to 10, and submit the following answers :—

"*Answer to Question* 1.—Other conditions being the same, the tendency to sludge formation is accelerated by an increase of temperature. Sludging is, we believe, a purely chemical reaction between certain unsaturated hydrocarbons present in the oil and the oxygen of the atmosphere. An oil kept at an elevated temperature (say up to 150° C.) and in the dark, will, we believe, show no tendency to sludge formation provided it is quite dry and out of contact with air. Our experience is that in transformers which are designed with tight covers and where the surface of the oil exposed to the atmosphere is a minimum, the oil sludges much less than in transformers running under the same conditions at the same temperature, but having a large surface of oil exposed to the atmosphere.

"*Answer to Question* 2.—Everything depends upon the degree of refinement of the oil and upon the conditions of the experiment. If it be true that oxygen is essential to sludge formation with any given oil, then, if the temperature be constant, the greater the surface exposed to the atmosphere the sooner will the formation of sludge be manifested. If the air be replaced by oxygen, or if the gas be bubbled through the oil, then sludge formation will be greatly accelerated (see also the Answer to Question 5).

[illegible] for an oil that would stand the above tests.

[illegible] compound of oxygen and some constituent of the oil, [illegible] without entailing the decomposition of the hydrocarbon. Cooling the transformer oil outside the transformer will tend to cause the deposit to settle in the cooler, and this means might be of temporary advantage, but the cooler [illegible]

"*Answer to Question* 5.—If the sludge that forms in transformers is due to the oxidation of certain constituents of the oil, as we think has now been proved by the work of Duckham, Dr. Michie, and others, then by keeping the surface of the oil in contact with an inert gas the formation of sludge would be almost entirely prevented. There would [illegible] transformer with a loose cover, but no doubt the difficulty [illegible]

"*Answer to Question* 6.—It is impossible to state any period before the tendency to sludging is manifested unless all the conditions are known, *e.g.* the type of transformer, whether it is designed so that the oil has a limited surface in contact with the atmosphere, whether the amount [illegible] the oil. All these conditions are found to affect the rate of sludge formation. It is also found that the presence of [illegible] formers contain considerable quantities of these metals exposed to the oil—greatly accelerate the formation of sludge. [illegible]

[illegible] properties of the oil. Assuming that no arcing has occurred in an oil which has been in use for some length of time, the following results are to be expected on testing :—

[illegible] it, but the [illegible] see the remarks at the end of th[illegible]

[illegible] manner [illegible] settles in the oil ducts and again retards heat transference by preventing the free flow of the oil.

[illegible] think that sludge alone [illegible] decrease in the specific resistance an[illegible] but with the clear oil left after the sludge has settled we do not find any alteration. Any lowering of these constants found in practice will usually prove to be due to the presence of moisture.

"Tests made recently on oil removed from [illegible] and that the dielectric [illegible] the oil surface exposed to the action of the atmosphere was extremely small.

[illegible]

made the conditions of the experiment must be carefully standardized.

"In our opinion an oil repeatedly heated to within say 90 per cent of its flash-point would not change to any appreciable extent, provided that oxygen and moisture were carefully excluded, and provided also that any volatile matter which is given off was condensed and allowed to to fall back into the oil, which should be well mixed again before testing. If the oil were heated as above in an atmosphere of a dry inert gas, but with no special provision for retaining the volatile vapours given off, then the specific gravity, viscosity, and flash point would rise, but the electrical properties would remain unchanged. If the oil is heated much above the flash-point with or without access of air, there is, in our opinion, some danger of decomposition taking place, and this would materially alter the physical properties. When air is not excluded, the oil is liable to sludge at very moderate temperatures. The temperature at, and the time in, which this sludging would be appreciable would depend upon the constitution of the oil.

"Some interesting results will be found on pages 310–24 of Archbutt and Deeley's book, "Lubrication and Lubricants," 1912, on the action of heat on various oils in the presence of air. In our opinion these results should form the basis of further series of experiments upon transformer oils. Although the oils mentioned are lubricating oils, yet we would point out that they are hydrocarbon oils and very similar to transformer oils; in fact a properly refined turbine oil is quite suitable for a transformer oil. It will be noticed from these tests how oils from different sources differ in the results obtained.

"*Answer to Question* 10.—We think that the question of sludging does not depend at all on the specific gravity or the viscosity. There is no reason why an oil of low specific gravity and viscosity should sludge more or less than one of higher specific gravity and viscosity if they are derived from the same crude oil and are refined to the same extent. It will be noticed that we state that the oil shall be from the same crude stock. Russian oils, for example, usually have a much higher viscosity than American oils of the same specific gravity, and so far as our experience goes the Russian oils also show a greater tendency to sludge."

The author considers the foregoing answers, based as they are on an almost unique experience, to be of such importance that they are quoted *in extenso*.

Mr. T. C. Thomsen, of the Vacuum Oil Company, writes as follows:—

"*Chemical.*—(1) With the best grades of transformer oils we have never known sludging to take place where the maximum temperature of the oil has been below 160° F., but other oils not specially treated for transformer service have been known to produce sludge at lower temperatures. If transformers were hermetically sealed, it is probable that the best transformer oils would work for long periods at higher temperatures, say 170° to 180° F.

"As transformers are practically always open, so that air, moisture, dirt, and dust have a comparatively easy access to the oil tanks, the present-day design of transformers lends itself towards causing trouble, as moisture decreases the insulating value of, and air, dirt, and dust have an oxidizing effect upon, the oil. Fine particles of dust attract to their surface a thin layer of pure oxygen, which, at high temperatures, will have an oxidizing effect on the oil.

"In the lubrication of steam turbines the oil, mixed with a certain small amount of water, air, and dirt, circulates at a high temperature in the bearings and at a low temperature in the oil cooler. If the temperature exceeds 140° F. we have found that with some oils sludging takes place due to the oxidizing influence of the impurities. As transformer oils are less liable to oxidize than turbine oils, the danger limit is undoubtedly higher than 140° F., probably in the neighbourhood of 160° F.

"As regards abnormal conditions of specially high temperature, such tests have been suggested by Mr. H. D. Symons, as follows:—

(1) Heat for six hours at 100° C.
(2) Heat for one hour at 200° C.
(3) Heat for six hours at 10 per cent above flash-point.
(4) Heat for four hours at 200° C.

"I would cite a special cooking test to which all our transformer oils are subjected at our refineries, as follows:—

"Heating the oil for one hour at a temperature gradually rising to 450° F. in an open vessel. The effect produced on the oil in these tests is not only due to temperature, but also to the oxidizing action of the air which has free access to its surface.

"(3) In my opinion 'abnormal conditions of specially high temperature' would mean temperatures of 160° to 200° F., and if it is proposed to devise laboratory tests to determine the amount of sludge a certain oil would produce under these conditions in actual service, I would recommend that such tests be carried out at the same temperatures as those existing during actual service. Such tests would be preferable to tests carried out at abnormal temperatures, as probably certain portions of the oil will decompose in these circumstances, and it would then be the products of decomposition which, affected by the oxidizing air, produce the sludge.

"I am of opinion that any cooking or oxidizing tests (either with air, oxygen, or ozone) carried out in a laboratory at higher temperatures than 200° F. are of doubtful value for practical purposes. It is probable that under such high-temperature tests some oils would produce sludge in the laboratory and yet would not do so under actual working conditions.

"If the analysis in Dr. Michie's paper of transformer oil deposit containing 16·9 per cent of oxygen in combination is representative of the chemical composition of sludge which has been found on occasions in transformers, it seems evident that the formation of sludge is due to oxidization.

"Examining now the conditions in an ordinary open-type transformer, since oxidization can only take place where the oil is in contact with the air, the formation of sludge will probably be directly proportional to the area of the surface of contact and probably also to the time the oil is exposed to the oxidizing influence. Finally sludge formation will probably only take place at temperatures above a certain critical value, which depends upon the nature of the oil and the design of the transformer.

"In order better to illustrate the kind of laboratory tests which I would prefer, consider a transformer containing, say, 1,000 gallons of oil, having a free oil surface of 20 sq. ft.

[illegible]

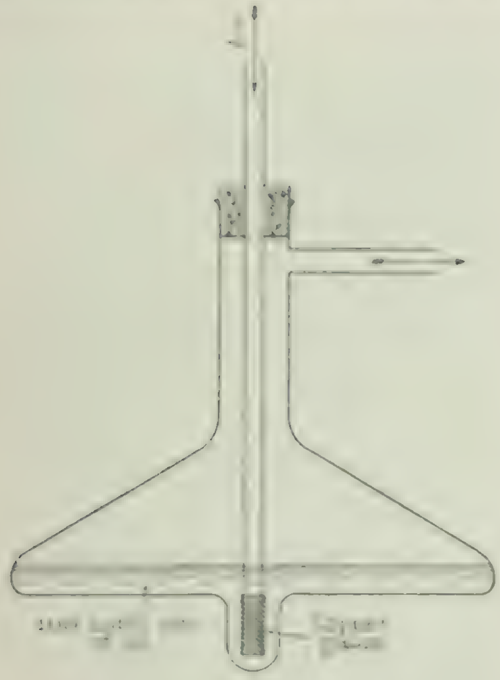


FIG. 1.

"[illegible] air through the oil in which copper is present, this metal has a catalytic effect, increasing the rate of oxidization [illegible]

"I consider it possible that the use of oxygen or ozone, instead of air, as an oxidizing medium, might be permitted in order to quicken the rate of oxidization, and tests could [illegible]

"Fig. 2 illustrates graphically the formation of sludge at [illegible] of oils, as tested by Dr. Michie. If [illegible] it would be possible to obtain diagrams which would illustrate very clearly at which temperatures sludge formation would commence to take place. This point I consider to [illegible]

[illegible]

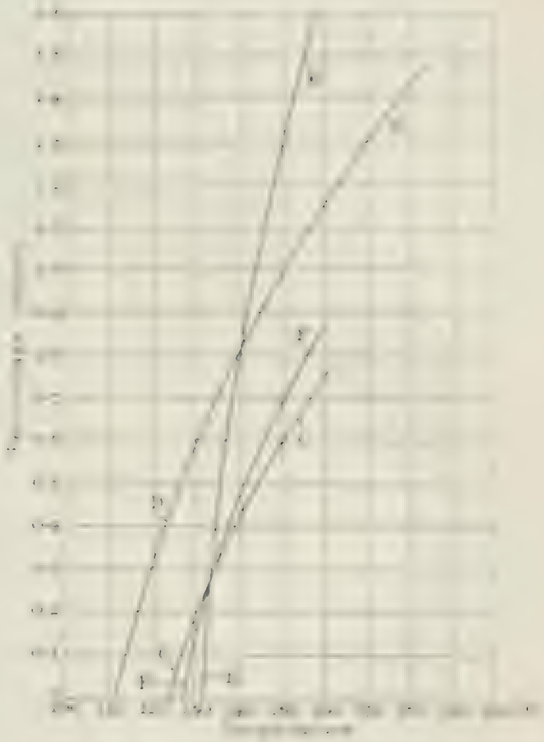


FIG. 2.

[illegible]

"[illegible] the oil, and it also seems prob[illegible]

[illegible]

"(4) If Question 4 infers the presence of a circulating and cooling system, I believe that effective cooling and sufficiently rapid circulation will certainly minimize or entirely prevent the formation of sludge, by reason of the lower and more uniform oil temperature.

"(5) In connection herewith, it may be interesting to quote an experiment made by Mr. F. Baxter, head chemist to the Vacuum Oil Company of Rochester, U.S.A. :—

"Two bottles of untreated transformer oil were exposed to the sun : one was hermetically sealed, and the other had a loose cork so that the air had free access to the oil surface. After a few days' exposure to the sun a deposit, which darkened in colour, appeared in the oil in the unsealed bottle, but the oil in the other bottle was unaffected. This experiment shows the oxidizing effect of air in the presence of sunlight.

"(6) *Physical.*—In America a maximum rise of 35° C. in temperature of the oil in a transformer above the temperature of the room represents current practice. In the United Kingdom 40° to 50° C., and on the Continent 60° C. is allowed. The highest temperatures occur in enclosed engine-rooms, such as underground sub-stations.

"An important change has taken place during the last few years, viz. that whereas the load on transformers used to be mainly due to lighting, the transformers being allowed to cool between the peak loads, a considerable portion of the load is now accounted for by motive power, so that transformers nowadays frequently get no rest during the 24 hours, the temperature being kept high continuously. If the oil sludges it is probable that sludging occurs very soon, although it may take several months before it is noticed, and cases have been known where sludging was observed with some oils after four months' to six months' use.

"(7) The formation of sludge indicates that the oil has broken down, and its decomposition is followed by increased viscosity and specific gravity. The flash-point is also slightly lowered, as is the thermal transference on account of the increased viscosity. As the formation of sludge increases, its accumulation in the oil ducts will retard the circulation of the oil and decrease the flow of heat from the coils.

"(8) The electrical properties of the oil are affected by the moisture absorbed from the air. If the air is warmer than the oil, water may condense directly on the oil surface, but the air is usually lower, or at least not higher, in temperature than the oil, and direct condensation of moisture cannot therefore occur. When a transformer is cooling, moisture may condense on the inside of the casing and so mix with the oil on its way to the bottom. The formation of sludge is probably largely or almost entirely due to the oxidizing effect of the air.

"(9) The alternate raising and lowering of the temperature of an oil occurs in turbine lubrication, and for the best turbine oils 140° F. is the maximum temperature below which the oil does not change appreciably in physical properties. Above 140° F. the specific gravity and viscosity increase, and the colour darkens, whilst the cold test, flash-point, and fire-point are unchanged. The percentage of petroleum acids increases. It must here be noted that the oil is under the influence of water, air, and dirt, in varying quantities, so that the above conditions are not exactly parallel with transformer conditions.

"We have made no experiments on transformer oils that directly answer the question, but some of them indicate that transformer oils properly made may be heated to 90 per cent of their initial flash-point for a considerable period without the formation of sludge or serious discoloration.

"(10) *Chemical and physical.*—Provided that transformer oils have been properly prepared, we see no reason why an oil of high specific gravity should cause sludge sooner or in greater quantities than an oil of low specific gravity; we rather think that the specific gravity is not an influencing factor."

The author suggests that to a certain extent it is possible that modern transformers with large oil surfaces in contact with the atmosphere may undergo profound modification in character, and that the Continental practice of employing closed transformers with expansion vessels having only a small surface in contact with the air is likely to be widely adopted in this country. Mr. Thomsen's method so far as it goes is a sound one if low test temperatures are accepted in the laboratory. Definite areas should be standardized for the exposed surface, and for the copper foil. It must also be remembered that with the ordinary English or American transformer of the type in which air is in contact with the surface of the oil, the rate of circulation of the oil throughout the oil tank may vary considerably for transformers of different makes but having the same rated output.

The author also suggests that the Thomsen test should be modified so that, while accepting a lower test temperature than is used by Dr. Michie (taking instead 60 per cent of the flash-point of the oil), the test should be conducted in a 110 cubic cm. flask with a long neck, but containing copper foil of a total area of 400 sq. cm. The oxidizing effect due to contact with the atmosphere will then be negligible, but there should be a suitable rate of air flow—say two litres per hour—definitely standardized.

High temperature laboratory tests are also deprecated. Unless the working temperatures of transformers are raised more than is now customary in England, or until it is possible to express the ratio between a high temperature test extending over some hours and the actual results of months and perhaps years of working at relatively low temperatures, there does not seem to be sufficient justification for tests at, say, 150° C.

Section B.—Absorption of Moisture.

In regard to Questions 11 and 12 Messrs. Ferranti refer to the use of anhydrous copper sulphate as an indicator of moisture, and also to the immersion in the oil of an iron rod heated just below a dull red heat for the same purpose. They also quote from the *Proceedings* of the Eighth International Congress of Applied Chemistry in 1912 four methods of determining moisture.

The Victoria Falls & Transvaal Power Company write as follows :—

"The amount of moisture that is absorbed by a pure hydrocarbon oil is very small indeed. An oil saturated with moisture would probably contain something like 0·005 per cent of water in solution, but it might contain more than this in a very finely suspended state. If the oil is continually exposing fresh surfaces to a very damp

[illegible]

in this way.

[illegible] impossible to lay down a chemical standard for a dry oil. In our opinion the best standard would be based on the dielectric strength and the specific resistance. An oil, the dielectric strength of which is such that the pressure [illegible] 8 in. below the surface of the oil is of the order of 35,000 to 40,000 volts, or the specific resistance of which is from 3,000,000 to 4,000,000 megohms per cubic cm. when measured at 15° C. through a film 10 mils in thickness, may be taken as a perfectly dry oil.

"A very small percentage of moisture in an oil is sufficient to reduce the dielectric strength and specific resistance enormously. Larger percentages of moisture, either in solution or in suspension, still further reduce these properties, but not in the same proportion as the first small increment."

Mr. T. C. Thomsen suggests that the only accurate test for determining the presence of moisture in transformer oils is by testing the dielectric strength and specific resistance. He also quotes an exceedingly interesting quantitative application of the copper-sulphate test devised by Mr. Philipps, chief chemist of the Powell Duffryn Coal Company.

In view of the fact that both the Victoria Falls Company and Mr. Thomsen favour electrical tests rather than chemical standards, the author desires to state that, in his opinion, a satisfactory minimum requirement as to what constitutes a dry oil at 15° C. would be defined by a specific resistance of not less than 2,000,000 megohms per cubic cm. and a dielectric strength of not less than 10,000 volts between a needle-point and a disc ½ in. in diameter, the disc and needle-point being [illegible] apart. An oil passing this test will not show any signs of moisture if tested by any of the usual chemical methods.

[illegible]

[illegible] ing than if [illegible]

[illegible] vertically. On account of the very [illegible] whereby we have obtained more uniform results. Provided that any stray pieces of fibre, etc., are removed from [illegible]

[illegible] same breakdown voltage, and that spherical electrodes are more difficult to clean than the needle-and-plate. More- [illegible] local heating to some extent, and the breakdown is not so [illegible] it is with spherical electrodes. For these reasons there is less chance of the lining-up of the particles which might be in suspension. The only troublesome feature is the [illegible] before immersion. The same treatment should be given to spherical electrodes (if employed to give the maximum potential gradient at the breakdown of the oil). Minute air-bubbles, or a film of moisture condensed on the electrodes, will affect the test results.

[illegible] small spark passed without an arc following. Arcing [illegible] spherical electrodes the arc always follows the spark.

[illegible]

This brings the breakdown voltage within the limits of the pressures of modern commercial high-tension transformers. A good oil requires a pressure of 11 to 13 kilovolts for a 0·125 in. gap. The writer prefers the longer gap, as small errors in measurement are of less importance.

"The cylindrical containing vessel for a gap of 0·2 in. and needle-point-and-plate electrodes should be about 2 in. in diameter.

"The test can be made almost immediately after pouring in the oil and adjusting the gap distance. Various intervals of time before applying the electric pressure were tried by the writer, from a few minutes up to 48 hours. No difference in the first test results was observed, except when floating matter was present.

"If after the first test the plate electrode is brushed to remove the carbon, the needle replaced, and the oil shaken up, the subsequent 'breaks' require a higher voltage as a rule. The question arises: Which must be taken as the true breakdown voltage of the oil? Is it the first or the maximum? From a commercial point of view, obviously the first. If the oil were perfectly dry, would the subsequent tests on the punctured oil give higher results than the first test? The writer's results are too meagre to arrive at a conclusion on this point; some seem to show that subsequent 'breaks' would not occur at higher voltages than the first. In a great number of tests it was found that a sample of oil subjected to several successive arcs apparently gave an increase in the electric strength, which might be due to the absorption of moisture by the finely divided carbon."

The author is of opinion that the needle-point and disc are preferable, partly as within small distances this test gives a lower value than that obtained by using spheres or needle-points, and it also best approximates to the manner in which a transformer may arc across from the windings to a point in the core plates. He would also point out that so far no information is available as to the variation of dielectric strength with the immersion of the electrodes, or as to the effect of movement of the oil on the dielectric strength. An investigation on these points may so far as the first is concerned have an important bearing on the design of a standard apparatus for dielectric strength tests, and as regards the second may largely influence the design of oil-break switchgear.

Section D.—Thermal Transference.

In answer to Questions 15 and 16, the Victoria Falls & Transvaal Power Company state:—

"We do not know of any method in vogue for the estimation of the relative thermal transference of oils, and although an apparatus could probably be designed to give comparative figures, it would probably be found that these figures are in the same ratio as the viscosities of the oils. The specific heat of all hydrocarbon oils is practically the same—about 0·4 (water being unity). As a general rule it may be stated that oils of low viscosity conduct heat more rapidly than oils of a higher viscosity, owing to the fact that thin oils are more susceptible to convection currents.

"Possibly the varying nature of the constituents of different oils may have an effect upon the thermal transference, but we think that it will be found that the thermal transference will vary inversely as the viscosity. There are several standard forms of instruments for measuring viscosity, and if it is found that this statement holds good, the measurement of viscosity would suffice for the test for heat transference also.

"We think an apparatus could be devised for testing heat transference. For example, a metal vessel divided into two watertight compartments, one above the other, might be used. The vessel should be well lagged to prevent radiation, and suitable inlets and outlets should be made to each compartment, together with thermometer pockets. The lower compartment is filled with the oil to be tested and could be electrically heated by means of a flat coil lying on the bottom of the lower compartment. The upper vessel can be filled with water, or, probably, mercury. The thermometer in the upper vessel should measure the temperature of the surface of the liquid, and should always be immersed to the same depth in each test.

"The oils to be tested should be at the same initial temperature (say 15° C.) and care must be taken that the current through and the voltage across the coil is always the same. The upper liquid (water or mercury) should also be as nearly as possible at the same temperature as the oil to be tested. Then the time taken from switching on the current to raise the temperature of the upper surface of the water or mercury by a definite number of degrees (say 10° or 20° C.) would be a measure of heat transference; by making a test with water in the lower chamber and calling the result unity, we could perhaps arrive at some basis of comparison.

"Probably it would be better to construct the vessel of a non-conducting medium, such as porcelain, with the dividing partition of thin sheet metal, say iron (for mercury). The error likely to arise through conduction of heat through the sides of the containing vessel would then be very small.

"We think that the thermal transference does not depend to any definite extent on the specific gravity, and until it is proved that no other factor than viscosity enters into the question of thermal transference we think it is impossible to express the relative thermal transference as a function of the viscosity. As stated in our answer to Question 15, we think it probable that the heat transference will be found to be a function of the viscosity, but we think this statement ought to be proved experimentally."

Mr. T. C. Thomsen also suggests a method of ascertaining the relative thermal transference of this oil:—

"Omitting for the moment transformers where the oil is circulated by means of a pump, the transference of heat through the oil usually takes place by a convection circulation of the oil, due to that part in contact with the transformer windings absorbing heat and rising to the surface whilst the part near the inside of the transformer casing cools and sinks to the bottom. The circulation of the oil is due to the change in specific gravity caused by the change in temperature; hence it is not the specific gravity of the oil that matters, but the coefficient of expansion, as the more the oil expands under the influence of heat, the more its specific gravity changes and the more rapid the circulation will be. High viscosity of the oil means slow circulation.

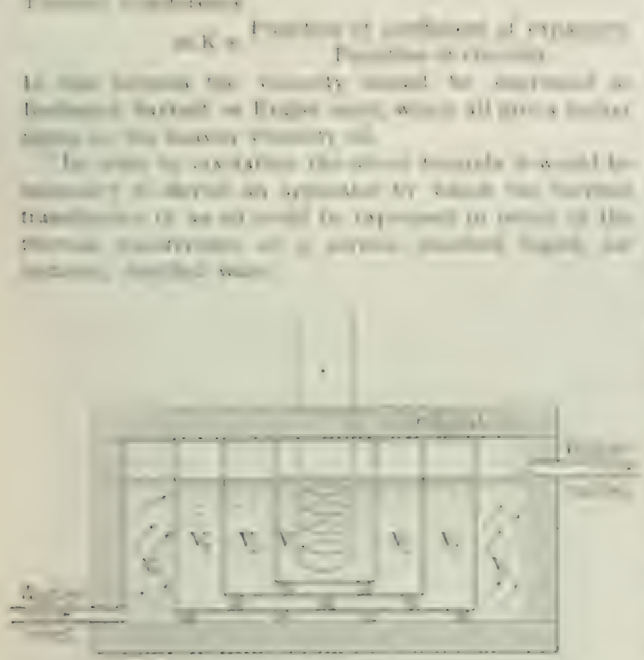
"As the transference of heat undoubtedly is greatly accelerated by increased speed of circulation, I believe it

[illegible] thermal transference of [illegible] coefficient of expansion [illegible]

Thermal [illegible]

[illegible]

[illegible]



[illegible]

"Fig. [illegible] gest might prove useful in this connection. The centre receptacle, V_1, contains a liquid which can be heated by electrical means to any desired temperature. This vessel [illegible] material at the bottom. This vessel is filled with the oil to be tested. Outside is another vessel, V_3, filled with water, and finally there is a water-jacket, V_4, through which a small, known quantity of water is passed continuously. Thermometers are fixed in the various vessels and the apparatus is covered by insulating material to prevent heat [illegible] constant the amount of heat passing from the inner vessel [illegible] the liquids in the vessels V_1, V_2, V_3, assume temperatures T_1, T_2, T_3, the area of the cylindrical surfaces being S_1, S_2, S_3, the thermal transference of oil O_t, and the thermal transference of water W_t, K_1 and K_2 being constants, the [illegible] passing through the vessels per hour being called H :—

$$H = K_1 S_1 O_t (T_1 - T_2) = K_2 S_2 W_t (T_2 - T_3)$$

[illegible] $W_t = 1$:—

$$O_t = \frac{K_2 S_2 (T_2 - T_3)}{K_1 S_1 (T_1 - T_2)} = K \frac{T_2 - T_3}{T_1 - T_2}$$

"In order to find the value of the constant K it becomes necessary to make an experiment, using water in vessel V_2, which experiment will give us the following equation :—

$$\frac{W_t}{W_t} = K \frac{T_2 - T_3}{T_1 - T_2} = 1 \text{ so that } K = \frac{T_1 - T_2}{T_2 - T_3}$$

"Once having determined K, the thermal transference of oil [illegible]

[illegible] through per hour, multiplied by the d[illegible]

[illegible]

[illegible] viscosity, the greater will be the percentage of c[illegible] oil, and as these increase the greater will be the quantity of carbon produced.

"In [illegible] size of the arc, the length of [illegible] on, that the question as to what happens when the oil is [illegible] of an oil constant when there is an arc beneath the surface.

"The composition of the oil would also have an effect upon the amount of carbon produced under similar conditions in oils from the same crude stock, so that oils [illegible] quantity would probably produce more carbon than oils of the same viscosity, but consisting chiefly of saturated [illegible] an arc under transformer oil were analysed, it was found that there was 62 per cent of hydrogen and 4·2 per cent of hydrocarbons (calculated as methane). The balance was stated to be nitrogen, but as the oil contains [illegible]

[illegible] temperature of the arc, and as in all c[illegible] the requisite volume of air or oxygen, we think that the actual composition is not a matter of large importance.

[illegible]

materially changed. Of course if nitric acid forms and is condensed on the surface of the oil it may cause trouble due to its action on the materials of construction of the transformer.

"Ozone, however, is different. The amount produced is also small, but it would undoubtedly accelerate the oxidation of the oil, that is, the oil would sludge more rapidly. We think that in neither case would the tendency to absorb moisture be increased."

Mr. T. C. Thomsen, having suggested that the methods used by Messrs. Digby and Mellis should be applied in connection with all of the various oils dealt with by those who co-operate with the Committee, has promised to contribute at a later date some information on the relative effects of continuous and alternating currents in occasioning carbonization.

In concluding this first interim report the author would like to express on behalf of the Sub-committee the indebtedness of the Institution to those three contributors whose opinions are so extensively quoted. The Sub-committee would greatly appreciate the continued assistance of these contributors and it invites others to express their opinions and give actual results. This, together with the programme of work which has been outlined, will, it is hoped, enable the Sub-committee to recommend standard tests in many, if not in all, the matters in regard to which opinion has hitherto been exceedingly diverse.

The Sub-committee would be glad to receive any figures bearing on the matters discussed in the Answers of the Victoria Falls & Transvaal Power Company to Questions 1—10 (Section A). They would also welcome assistance, from those collaborating in this research, in the application of Mr. Thomsen's suggested sludging test and its co-relation with the figures obtained by Dr. Michie's test; and also in carrying out tests on the lines suggested by Mr. Thomsen under Section D. In applying Mr. Thomsen's formula they would suggest that the range of test temperatures, for which the value of the coefficient K should be determined, might be from 15° to 50° C., and from 15° to 75° C.

The author suggests that an alternative device for determining the value of the coefficient K would be in the employment of a spherical vessel filled with oil to half its volume. If this were immersed in a larger vessel, containing water heated by an electrical resistance, and the cold and hot junctions of a thermo-couple placed exactly in the centre of the oil and the surrounding water respectively (a thermometer reading in tenths of 1° C. being also placed in the water) the temperature lag of the oil behind the temperature of the water would, measured at regular successive intervals, perhaps be the best index as to thermal transference. So far as the actual operation of transformers without artificial circulation is concerned, thermal transference must be regarded as distinct from thermal conductivity on account of the part played by convection currents.

EXTRACTS FROM THE "KING COUNTRY CHRONICLE" NEWSPAPER (NEW ZEALAND), AND THE NEW ZEALAND POLICE OFFENCES ACT.

The following two extracts are from the *King Country Chronicle*, of Te Kuiti, New Zealand. The first appeared in the issue of the 17th June, 1914, and the second in the issue of the 15th July, 1914:—

An Unusual Charge.

[A defendant] was charged with a breach of the Police Offences Act by using the letters A.M.I.E.E. after his name, not being entitled to do so.

Sergeant Rowell, for the prosecution, said the proceedings had been taken at the instigation of the Institution of Electrical Engineers. It had been ascertained by the secretary of the New Zealand branch of the Institution that defendant never had been a member of the Institution, and defendant had been written to concerning the matter. Defendant had stated that he had made use of the letters under the impression he was entitled to do so, but he had subsequently written stating he was in the wrong.

Mr. Sharples, who appeared for defendant, pleaded guilty. He explained that defendant had been called away to attend to urgent business and could not attend. He was instructed that defendant became an Associate of the Institution in Australia, and thought he was entitled to use the letters, except for the fact that he was not a financial member of the Institution.

His Worship said he could not accept the statement made by defendant's counsel in face of the letter defendant had written, but would grant an adjournment till next court day to enable defendant to appear.

An Unusual Charge.

[A defendant], who was charged at last Court with wrongfully using the letters A.M.I.E.E. after his name, did not appear, but sent a letter to the clerk of the court. Mr. Sharples, who appeared for defendant last court day, stated defendant had withdrawn his retainer, and he was therefore unrepresented by counsel. A fine of £5 and costs was inflicted.

New Zealand Police Offences Act.

Section 20 of the New Zealand Police Offences Act (1908, No. 146) is as follows:—

20. (1) Every person commits an offence and is liable to a fine not exceeding twenty pounds who publicly uses in connection with his business, trade, calling, or profession any written words, initials, or abbreviation of words intended or likely to cause any person to believe, contrary to the fact, that he holds a degree, diploma, or certificate granted or issued by any university or other institution, society, or association, whether in New Zealand or elsewhere, or that he is a member, associate, or fellow of any such association, society, or association.

(2) In every prosecution for an offence against this section the burden of proving that the defendant holds such degree, diploma, or certificate, or is a member, associate, or fellow of any such institution, society, or association, shall be on the defendant.

(3) It shall be no defence in any prosecution under this section that the words, initials, or abbreviation so used by the defendant do not refer or profess to refer, or were not understood by any person to refer, to any particular or actual university, institution, society, or association.

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AUTOMATIC PROTECTIVE SWITCHGEAR FOR ALTERNATING CURRENT SYSTEMS.

By E. B. Wedmore, Member.

[illegible]

Introduction.

[illegible]

The author proposes to consider the general conditions governing the choice and design of protective devices of this kind, and to describe some of the more generally useful devices now available. In order to complete the [illegible] devices, but it is hoped that the treatment of them will be [illegible]

Commercial considerations must ultimately decide the use of any apparatus. For example, on distributing systems employing only a few miles of cable the prob[illegible] commercially practicable to employ apparatus requiring special knowledge for its efficient maintenance. Even on such a system, however, a reputation for continuity of [illegible] some expenditure on selective protective apparatus.

In such a case, too, probable future developments must be [illegible] its present dimensions, there are likely to be at least five times as many faults per annum, and the results of indi[illegible] installation, excessive expenditure or loss will be incurred later on.

The use of protective devices acting selectively to cut out faulty sections will not only ensure continuity of supply, but by enabling faults to be cleared quickly and whilst only a small current is flowing, will greatly reduce their destructive effects. It is only owing to imperfections [illegible] not become uni[illegible]

[illegible] devices often enables economies in the expenditure on [illegible] the expenditure on the [illegible]

The expenditure on cables is [illegible] third to one-half of the total capital [illegible] to heating, the cables are generally run at a lower current [illegible] law; yet in order to ensure continuity of supply with indifferent apparatus it has been the practice to duplicate [illegible] ment of the cables [illegible] apparatus.

[illegible]

[illegible]

(1) [illegible]

(2) [illegible] reverse direction to [illegible]

(3) [illegible] channels.

[illegible]

on independent circuits they prove inadequate where the supply circuits are duplicated.

Fig. 1 shows the elements of which distribution systems are constructed, and will serve to define the terms employed. The supply to the point A is through an independent feeder. The supply to B is duplicated by the use of parallel feeders, whilst that to C and D is

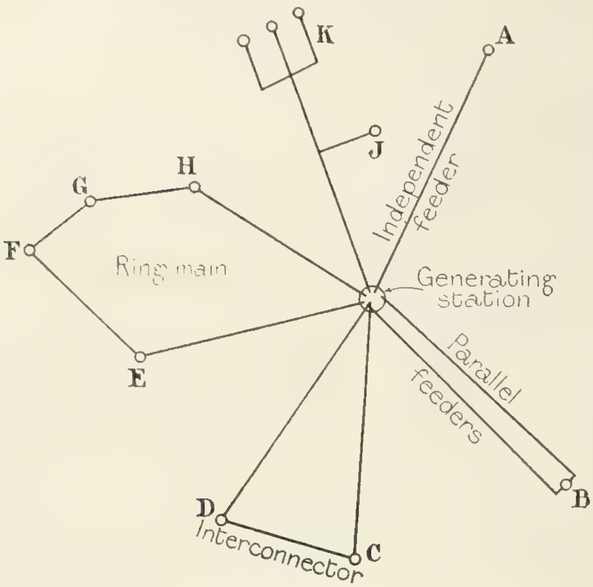


Fig. 1.—Elements of Distribution System.

duplicated by the use of an interconnector. The normal energy-flow in feeders will be from the source outwards, whilst in interconnectors the flow may be in either direction, varying with the load conditions. Trunk mains to a distributing centre are parallel feeders, but trunk mains between two generating stations are parallel interconnectors. The ring main, feeding points E, F, G, and H, is a combination of feeders and interconnectors, the connection between any two of the distribution points being an interconnector. At each distribution point the circuits supplying individual motors, etc., or isolated transformers, are independent feeders (such connections are so short and laid under such favourable conditions that it is unnecessary to duplicate them).

All distribution systems are built up of combinations of the above. Independent feeders may be branched as at J and K, but are still considered as independent feeders or open ended. The closed figures giving a duplicate supply may be combined into networks.

In independent feeders a fault is characterized by an increase of the current in the normal direction in the individual feeder, and may be removed from the system by disconnecting the feeder at the end nearest to the source of supply.

In closed systems, on the other hand, a fault on any feeder will cause an increase of current through the duplicate source of supply, varying in amount with the position of the fault.

Protection of Independent Feeders.

In the case of independent feeders it is impossible to remove the fault without causing a temporary loss of supply to that part fed by the faulty feeder; but trouble should be confined to the part in question, although this is not always done.

The following devices are employed for the purpose :—

Simple overload devices.—Fuses are satisfactory for small circuits, but are replaced by automatic circuit-breakers on large circuits in order to obtain better rupturing characteristics, and to save delay and expense in restoring the circuit. If instantaneous in operation, circuit-breakers must be set high enough not to be disturbed by momentary heavy overloads incidental to the service. It is found that most circuits, and especially power circuits, are subject to such momentary overloads, and in order to prevent loss of supply it is necessary to adjust the overload devices to withstand perhaps several times normal load. Such an arrangement necessitates all faults being retained on the circuit until they become heavy faults, and it may allow of serious injury to the plant on a sustained overload.

Time-limit overload devices.—This difficulty is partly met by the use of time-limit overload devices. The destructive heating will require a time roughly inversely proportional to the square of the current. A circuit-breaker having an inverse time characteristic suitably adjusted would permit the plant to deal with any condition that it can safely meet, and it would disconnect the circuit at any overload on the danger-point being approached. This at any rate is the ideal aimed at and the justification for the use of an inverse time characteristic. In practice one relies on the attendant to prevent continuous overloading.

Leakage devices.—A leak may occur between poles or to earth. A leak between poles generally develops into a short-circuit. At the source of supply it is indistinguishable from an overload, and the case is met by the use of overload devices.

A leak to earth may not cause overloading, and thus may continue for a long time on a circuit protected only by overload devices. This introduces a risk of fire or shock, serious in mining work and undesirable in all cases. In case the leak is through combustible insulating materials, as in machines or cables, it will probably develop into a short-circuit between phases. On the large distributing systems of to-day, and the larger systems of to-morrow, it is becoming and will become increasingly important to provide means for disconnecting, before the short-circuit stage is reached, sections on which there are leakages.

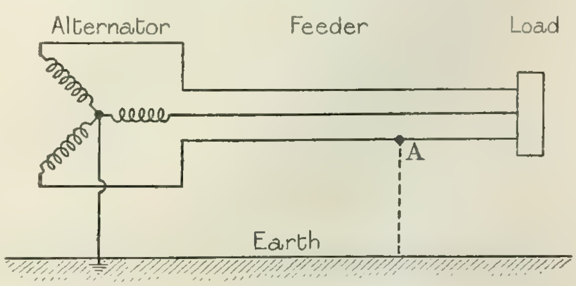
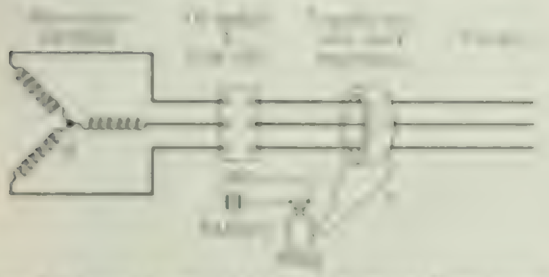


Fig. 2.—Three-phase Feeder with Leak to Earth.

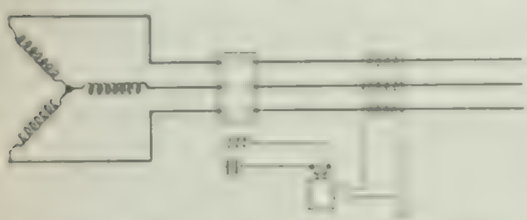
Fig. 2 represents an independent 3-phase feeder having a leak to earth at the point A. It will be observed that prior to the leak all current going out through one of the conductors must return through the others, and that

[illegible]



[illegible]

In another form separate transformers are furnished, one [illegible] nductor, and the tripping device is connected in [illegible]



[illegible]

ment direct-acting trip coils can commonly be employed, [illegible] at about one-third of normal load, and the same [illegible] ers may be employed to excite instruments and to operate the usual time-limit overload devices which are still necessary to protect the system against faults between [illegible] combination for this purpose, in which the time-limit over- [illegible]

[illegible] value and should be used universally on inde- [illegible] h.t. feeders, and on high-tension service where current transformers are available, or the slight additional cost of supplying them is justified. The arrangement not [illegible] res the early disconnection of faulty circuits, but enables the fault to be removed from the system with a minimum of disturbance.

The ability to remove faults quickly and before the [illegible]

[illegible]

[illegible]

[illegible] a current-limiting resistance the core-balancing system [illegible] positively limiting the fault current to earth to a relatively small figure. Where core-balancing devices are not employed, the earthing resistance must allow a sufficiently large current to pass to operate the overload devices with the highest current settings which may be employed on [illegible] short-circuit to earth the current which flows represents only a temporary increase of load of less than 200 kw.

[illegible]

The introduction of core-balancing apparatus enables selective action to be obtained to an extent quite impossible with overload devices. At the generating station [illegible] generating plant and of the individual user generally results in practice in an arrangement giving no selective action.

With leakage protective gear, however, used in combination with a suitable limiting resistance, the conditions [illegible]

the generating plant for several seconds or more without danger, whilst at the consumer's end the device may be set to operate instantaneously at a fraction of normal load without any danger of its causing a disconnection during momentary overloads. The settings of the automatic devices in series between the generators and the local supply circuits can be graded in large steps of current and time without sacrificing the requirements at either end.

Use of Fixed Time-limit Relays.

Fixed time-limit relays have been employed successfully to get selective action between switches near to and others remote from the source of supply. There is one essential condition of success, namely, that the difference in time setting between two consecutive switches must be sufficient to admit of one switch completely disconnecting the circuit before the other commences to operate. There are several stages in the operation, as follows :—

(1) Action of the tripping device.
(2) Separation of the switch contacts after the catch is released.
(3) Breaking the circuit after the contacts are separated.
(4) Cessation of movement of the relay after the circuit is opened.

The total will generally lie between ¼ second and 1 second according to the design. To this must be added a margin for safety.

The several relays in series must be adjusted to give this time interval between the action of each and the next. The heaviest faults will be those near the generating station, and yet these must remain on the system for the maximum time, perhaps for several seconds. If leakage tripping devices are substituted, however, fixed time-limit delaying attachments can be used with great advantage as they ensure positive selective action, and there is but little objection to allowing the limited fault current to flow in the system for the necessary interval.

The Earth Connection.

All 3-phase systems have their mid-point earthed through the star-connected condensers formed by the capacity of the cable, and on a fault to earth a corresponding capacity current will flow which may be quite sufficient to operate core-balancing apparatus.

If an earthing resistance is used, as is generally the case, it must allow a current to pass substantially larger than the minimum required to operate the automatic releases of the switches so as to ensure the quick development of the fault and proper action in case the fault is of relatively high resistance.

To keep down static disturbances the resistance should be an effective shunt to the star capacity of the system, but there are insufficient data on metallic arcs in air and oil for us to lay down rules on this point.

A high resistance absorbs less energy and is likely to be cheaper. The section of metal should, however, possess ample mechanical strength. It is recommended that on e.h.t. systems the resistance should not pass less than 50 amperes, or 100 amperes on high-tension and medium-tension systems. In practice the current required is generally higher than this on account of the higher settings of the automatic releases in large generator switches.

We are considering the protection of independent feeders, but it is convenient to digress at this point to draw attention to the current required to be carried by the earthing resistance in the case of parallel feeders.

If these are feeders in parallel protected at both ends by overload or leakage devices, it should be noted that if a fault occurs on one of them near that end remote from the source of supply the fault current may be shared nearly equally between them, and as each will carry only its share of the current this share must be sufficient to operate the protective apparatus. For example, two 0·1 sq. in. feeders with overload devices set at 300 amperes will have to carry a fault current of 600 amperes before these devices operate, so that allowing a margin of safety the resistance would have to pass say 800 amperes. With leakage protection this could be reduced to a total of 100 amperes, *i.e.* 50 amperes per feeder. These figures show an error in the common statement that the resistance should pass a current corresponding to the setting of the automatic with the highest setting.

It has been shown that the use of leakage devices on feeder circuits has many advantages, and it remains to say that when core-balancing apparatus is applicable it will always give better results than overload devices.

Leakage Protection for Sources of Supply.

Hitherto we have been considering independent feeders conveying current to individual distributing or consuming points. The core-balancing principle has, however, been applied recently to independent feeders conveying current from sources of supply.

Fig. 3 shows the device applied to an outgoing circuit, and it will be seen that if the insulation of the generator breaks down to earth the balance of current in the lines is unaffected and the switch does not operate. If, however, the conductor from the generator's neutral point to earth is included in the core-balancing transformer as in Fig. 6, it will be found that the transformer is now

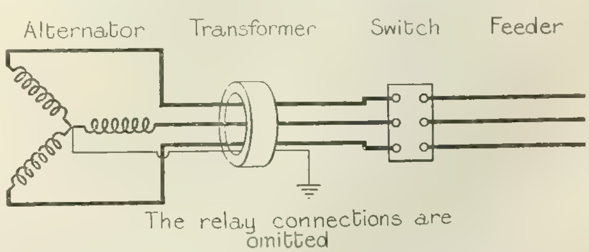


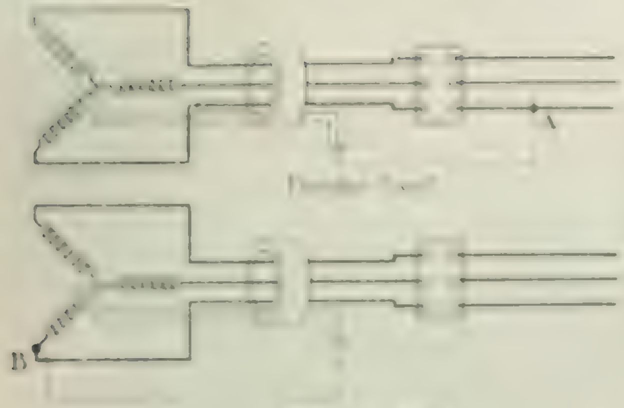
Fig. 6.—Source of Supply protected by Core-balancing.

unaffected by a feeder fault, but is affected by a fault in the machine or on the machine side of the transformer.

Fig. 7, A, shows the feeder fault, and it will be seen that the fault current represented by the dotted line goes out and returns through the balancing transformer, whereas Fig. 7, B, shows a generator fault sending current in one direction only through the transformer and thus upsetting the balance.

Thus core-balancing apparatus will cut out an individual faulty load circuit or source. Fig. 8 shows three machines and circuits so protected.

[illegible]



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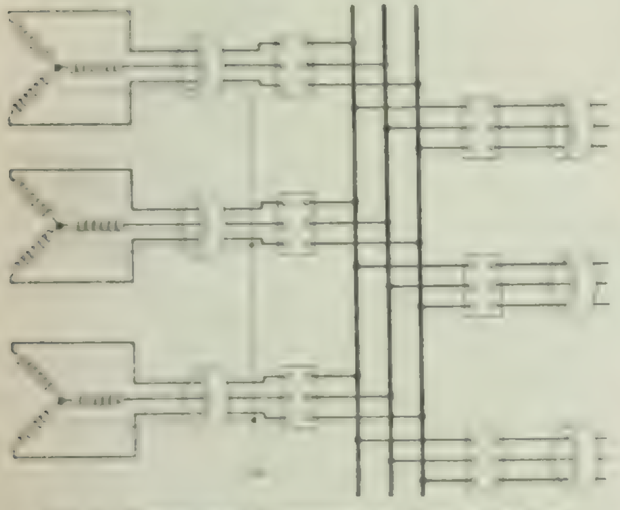


[illegible]

[illegible]

PROTECTION OF PARALLEL FEEDERS.

[illegible] nearest the generating station, and reverse-current devices [illegible]

[illegible] reverse-current relays that [illegible]

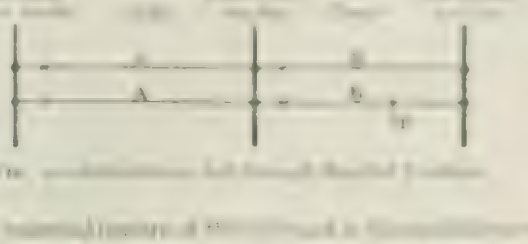
(1) [illegible] in an e.h.t. feeder.

(2) [illegible]

(3) Some so-called discriminating relays are liable to [illegible] cially on the sudden removal of a fault. This [illegible] to severe tests under actual working conditions.

Several attempts have been made to get over these [illegible] general solution of the problem they are worthy of further consideration. The more important devices will now be described.

[illegible] is that which has been [illegible] based on the principle that [illegible] current equally. If the relays are arranged so that they [illegible] arrangement should be proof against all conditions not accompanied by breakdown of one of the feeders in [illegible] indirect interlocking, whether by mechanical or electro- [illegible] forces, and many combinations have been devised for the purpose since the idea was first propounded. It is not intended to describe all that has been done.



[illegible] between the apparatus [illegible]

[illegible]

stations fed in series through pairs of parallel feeders A, A, and B, B, from a generating station, the feeders being protected by overload devices at the points marked X. The protection for the remote end is dealt with later.

If the overload devices in each phase are interlocked as described above, it will be seen that they will be unaffected by any fault on the system other than one in the individual pair of feeders. For example, a fault in either sub-station will be fed equally through the feeders in either pair whether from the source of supply or from running machinery returning current. If a fault occurs at P in feeders B, B, the feeders A, A, will still carry equal currents and only feeders B, B, will be affected.

A further device is required to discriminate between the two feeders B, B, and this may be obtained by arranging that the more heavily loaded feeder shall be cut out, for it will be seen in the example illustrated that the faulty feeder will carry most of the fault current. This is shown

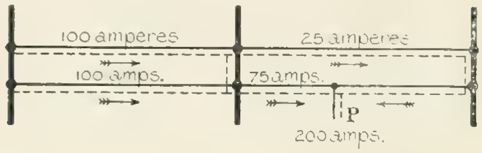


FIG. 10.—Distribution of Fault Current in Parallel Feeders.

in Fig. 10, in which the fault currents have been added, assuming a fault to earth of 200 amperes.

Fig. 11 shows diagrammatically a relay having the required characteristics. The operating coils are excited respectively from the two feeders, and the balance arm is biased to the middle position. So long as the currents are equal the balance arm will be unaffected, but with an increase

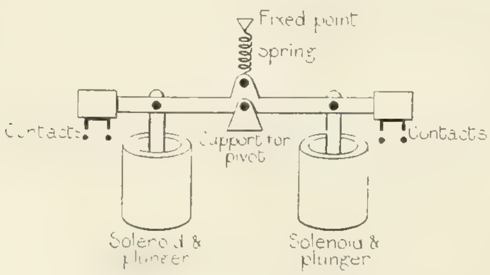


FIG. 11.—Balanced Overload Relay.

of current on one side the arm will be drawn down on that side and will close the corresponding pair of contacts to trip the switch in the feeder on that side.

On the faulty feeder being disconnected, the other becomes the more heavily loaded and some device is required to prevent its being disconnected. The relay can be arranged to require resetting by hand, but the relay must then be cut out whilst a feeder switch is replaced, and in case the feeder fails at that moment there will be no protection.

The only sound method is to employ auxiliary switches on the oil-switch mechanism to bring the coils into action automatically. Satisfactory service has been given by such a device which automatically converts the protection into time-limit overload protection on one feeder on the failure of, or the deliberate disconnection of, the other.

Sensitiveness of interlocked relays.—In practice a perfect balance of current between the feeders is not obtainable and there will be an appreciable excess current on one side or the other on a severe overload. If now the maximum short-circuit current is 100 times the normal load in each feeder, and the feeders balance within 1 per cent, there will be on a dead short-circuit a difference current equal to the normal load current, and the relays must not operate under these conditions.

In practice the short-circuit current may exceed this value considerably, and on the other hand it is desired to cut out faults to earth with a moderate current flowing. This necessitates means for accurate balancing.

The balancing difficulty can, however, be completely eliminated by a simple device which has been employed successfully on e.h.t. service. Each feeder is furnished with a relay having two elements, one an operating element and the other a restraining element, as for example in Fig. 12.

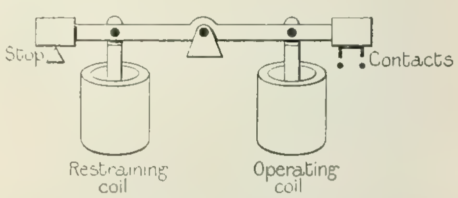


FIG. 12.—Biased Protective Relay.

The operating coil is excited from the feeder which is being protected, and the restraining coil by the feeder in parallel with it. The arrangement is biased in favour of the restraining coil to the extent of say 10 per cent, by placing extra turns on that coil so as to make it more powerful than the operating coil by 10 per cent. Now unless the balance is upset by more than 10 per cent the device cannot operate, and yet at normal load the device tends to operate immediately the fault current exceeds 10 per cent of the normal load current. This eliminates all errors in balancing, whether in the relays, current transformers, or feeders, and also the maintenance of balance.

As interlocked overload relays are proof against overloads or faults occurring outside the parallel feeders protected, it will be seen that they are particularly suitable for the protection of a number of stations in series. All the devices may be set to operate instantaneously and at less than the normal load current, and yet none of them will operate except in the faulty section.

Interlocked leakage relays.—Another method of eliminating the balancing problem is by the use of leakage relays interlocked in the same way as overload relays. These relays as previously described operate only on faults to earth, of which the extent can be limited by an earthing resistance. The relay settings will be in the neighbourhood of the maximum fault current, and thus even a 10 per cent unbalancing is quite negligible. Seeing that most cable faults are faults to earth, and that of the faults between phases most develop first or simultaneously as faults to earth, this arrangement will successfully remove the large majority of feeder faults and is proof

[illegible]

[illegible] period.

[illegible] will be no extinction of the voltage on a fault to earth.

The difficulty due to loss of voltage has been dealt with in another way with promising results. One may almost count on having a working margin of voltage for at least a [illegible] the operation of the relay. This is effected by [illegible] parts unstable at low voltage, so that any movement initiated is completed. At full voltage the moving parts must be stable so as to ensure restoration of the relay and freedom from trouble due to vibration and sudden changes of load. Such relays have given satisfactory operation for a number of years.

These improvements render the reverse relay almost independent of voltage. The application of the interlocking idea renders them unaffected by current fed back from sub-station plant and of surges in either direction.

Fig. 13 illustrates diagrammatically the interlocking of a pair of reverse-current relays suitable for the control of the remote end of the feeders in Fig. 9. The current [illegible]ners in the two feeders are so connected that [illegible] normally circulates between them.

The relays and trip coils are connected in shunt to them. In case of unbalancing, the difference current is taken through the relay winding and contacts which are normally closed. The trip coils are in shunt across the respective relay contacts, thus a trip coil cannot be energized unless there is the combination of an unbalanced current due to leakage and the operation of the relay controlling that coil. The difference current is [illegible] failed, as to operate the relay on the faulty feeder and to restrain the other. Thus the faulty feeder is disconnected.

It will be found that even if reversal occurs in both feeders the relay carrying the fault current is the only one which will operate. The faulty feeder will carry the heavier reverse current, and thus the difference current [illegible]

FIG. 14.—[illegible]

W[illegible] potential windings will deal succe[illegible] of faults, it is to be noted that the f[illegible] cannot cope are just those most likely to occur as the result of bad design, bad workmanship, defective material, and carelessness, and are also those most disastrous in their results. Workmen omit to remove earthing [illegible] clearances and oil switches are made too small, [illegible] dead short-circuits occur. The relay makers cannot be blamed, but there is no satisfaction for the consumers whose power supply has been interrupted, or for the suppliers who have lost valuable plant.

[illegible]

As the energy flow in a sound interconnector or ring main may be in either direction, varying with the distribution of load, reversal is no longer a sign of leakage. A leak of sufficient magnitude ma[illegible] ends. This condition is a sure criterion of a heavy fault.

[illegible] selective action. Fig. 14 illustrates diagrammatically such [illegible] the individual relay. The tripping circuits are [illegible] circuit is completed only if both relays operate.

[illegible]

reverse relay with those of the pilot wire. It is inoperative except on faults large as compared with the load current, and means are required in practice to ensure the simultaneous operation of the pair of relays even under conditions of rapidly fluctuating energy flow, or the alternative of a positive delaying device to meet the same condition.

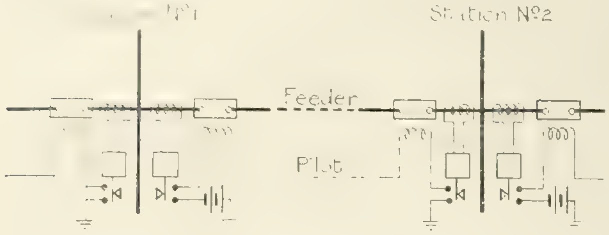


FIG. 14.—Protection of Interconnector by Discriminating Relays and Pilot Wire.

Connections are shown for one phase only.

THE BALANCED VOLTAGE AND CIRCULATING CURRENT SYSTEMS.

The pilot wire may be employed more profitably to take a sample of current from one end of the feeder to the other for use as a standard. The current at the remote end may then be compared with the sample to determine whether the direction or magnitude of flow is the same. The latter is the better course as the magnitude changes with the smallest leakage, but the direction will only change with a relatively large leakage.

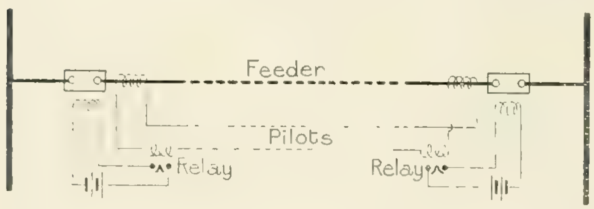
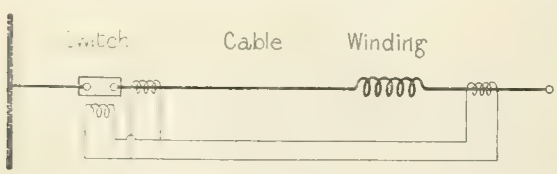


FIG. 15.—Protection of Interconnector by Balanced-voltage System.

Connections are shown for one phase only.



Connections are shown for one phase only

FIG. 16.—Machine Winding and Cable protected by Circulating-current System.

This is the basis of the well-known Merz-Price protective system. The input and output of a given feeder will always be equal unless there has been leakage either to earth or between phases. The comparison may be carried out in various ways, but in practice these have been resolved into two systems, namely, the balanced-voltage and the circulating-current systems.

Current transformers are inserted at the two ends of the conductor to be dealt with and are connected through the pilot wires. In the balanced voltage system diagrammatically illustrated in Fig. 15 the current transformers are connected in opposition and the relays in series with them. In the circulating-current system illustrated in Fig. 16 the transformers are so connected as to circulate the current between themselves under normal conditions. The trip coils are connected in shunt between equipotential points and carry only the difference current corresponding to the leak. The balanced-voltage system is best adapted for

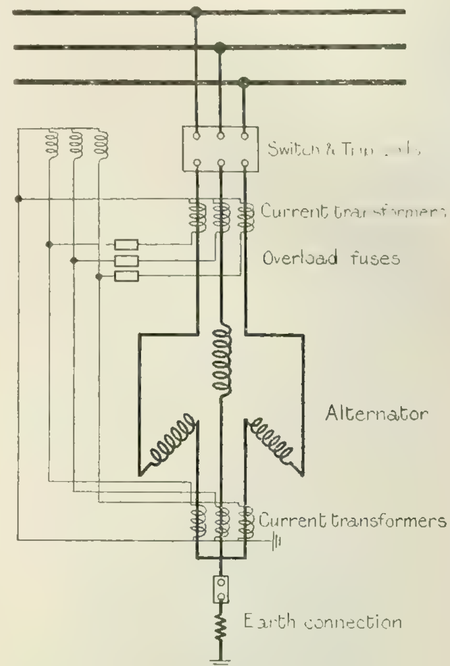


FIG. 17.—Alternator protected by Circulating-current System.

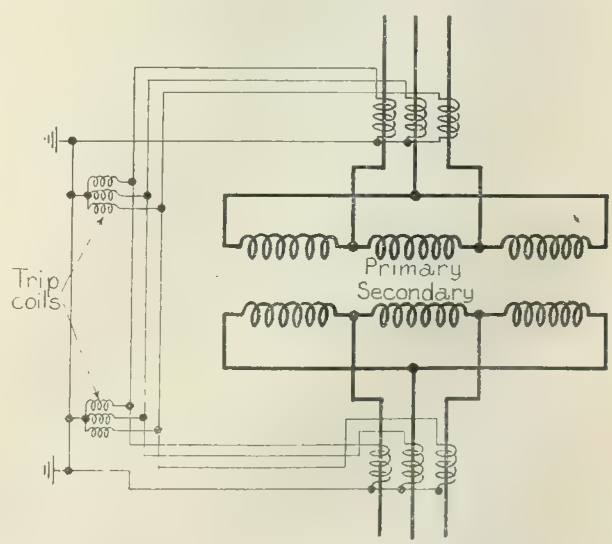
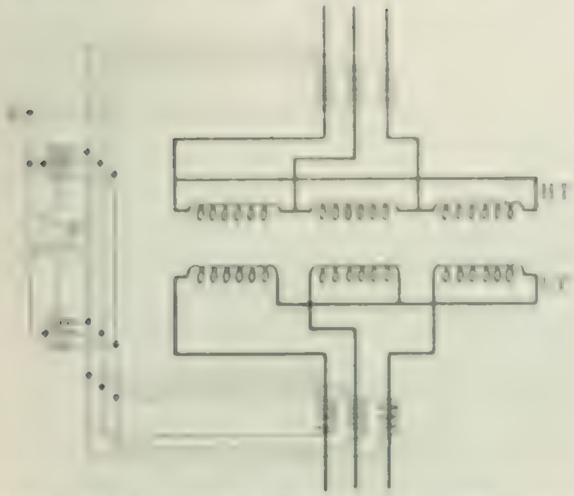


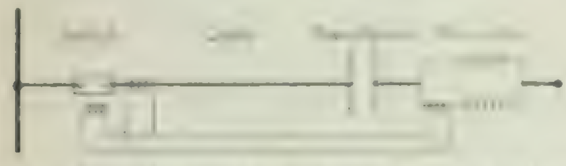
FIG. 18.—ΔΔ Transformer protected by Circulating-current System.

[illegible]



[illegible]

[illegible] unnecessary to enter into further details. Fig. 17 shows a typical arrangement for the protection of alternators, and [illegible] shows a novel combination for the protection of a large



[illegible]

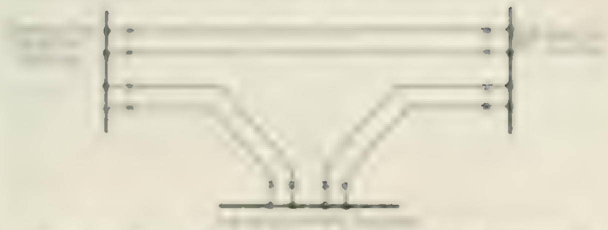
generator and a step-up transformer. The generator has [illegible] with the total output of the e.h.t. side of the transformer. Any change in the ratio of these will indicate a [illegible]

[illegible]

[illegible] protection of the parallel feeders may be obtained by the use of overload relays with the interlocking combination installed at both ends of the feeders, as the faulty feeder will always carry the heavier current at both ends.

This condition does not immediately apply, however. [illegible]

[illegible]



[illegible]

[illegible] current at the end remote from the source of supply. This necessitates that the relays should be ad[illegible] operate only on faults which are [illegible] uneconomical use of cable.

[illegible] deal with faults between phases.

[illegible]

character. We can obtain a technically and practically satisfactory combination by the use of interlocked excess-current devices at both ends of the pair of feeders and without further selective apparatus if we regard the pair of conductors as the unit of which the distributing system is to be composed.

For example, a ring main run in duplicate may be so protected. Seeing, however, that both conductors will be disconnected when a fault occurs in either, the economical solution is found in the ingenious suggestion of putting the two conductors in one cable and lightly insulating each from the other.

Split-conductor Protective System.

This gives us the split-conductor protective system and up to the present the best solution of the problem, for not only does this solution give an arrangement applicable to ring mains, interconnectors, and duplicate feeders—in fact, to all systems of distribution—but it gives an arrangement absolutely selective and so sensitive as to perform this function instantaneously at a fraction of the normal load current.

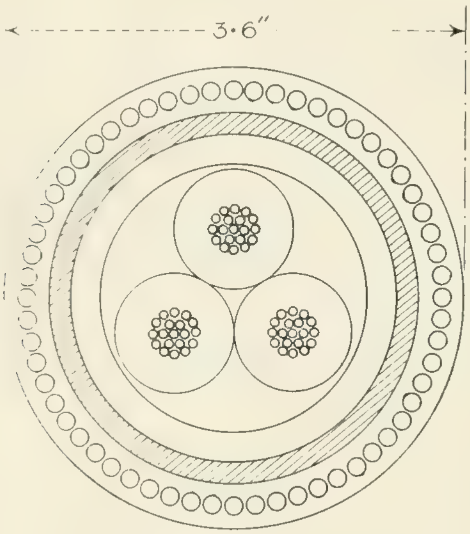


Fig. 22.—Standard 20,000-volt 0·1 sq. in. Cable

The system requires the employment of a cable of special construction, or in the case of overhead lines a special arrangement of conductors. The construction involves but a slight departure from that commonly employed, and consists in the splitting or separating of each conductor into two parallel portions lightly insulated from one another.

Fig. 22 herewith illustrates a standard 0·1 sq. in. cable suitable for 20,000-volt distribution. Fig. 23 illustrates a similar cable constructed for use under the new system, and it will be seen that each core is split (hence the name "Split-conductor protective system"). The cable is constructed with an oval concentric core, this construction giving the best distribution of potential strain in the insulation. In small sizes this is especially valuable, and dispenses with the necessity for a hemp core within the copper conductor. Such cables are being manufactured at a cost but slightly exceeding that of the standard pattern, suitable for a wide range of voltages and currents.

Principle of operation.—The principle of the system is illustrated diagrammatically by Fig. 24, which shows the connections for one split conductor. The split conductor is connected at each end to the usual switchgear equipment, consisting of oil switch, busbars, etc., through a special current transformer. The current-transformer core has two primary windings, to which the two halves of the split conductor are connected, and the core carries also a secondary winding connected to a relay controlling the oil-switch trip coil.

Under normal conditions, as in Fig. 24, current entering the feeder at one end divides equally between the two parallel paths, being united again on the remote side of the

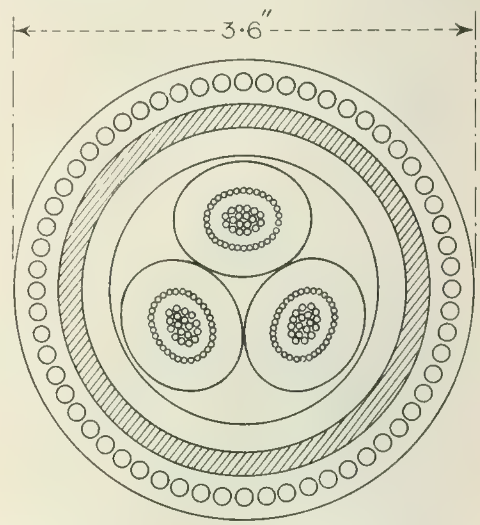


Fig. 23.—Standard 20,000-volt 0·1 sq. in. Split Conductor.

second current transformer. In each transformer the magnetizing effects of the two primary coils are equal and opposite, thus the transformer offers no impedance to the current flow, and the secondary windings and relays are unaffected.

In case, however, a fault develops, for example at the point A in Fig. 25, the fault current flowing towards A will

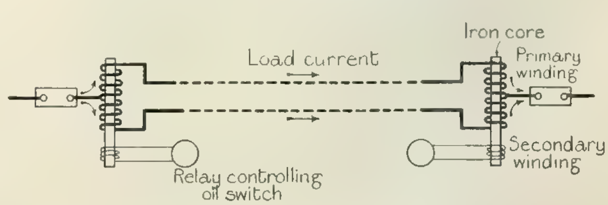


Fig. 24.—Split-conductor System—Sound Feeder.

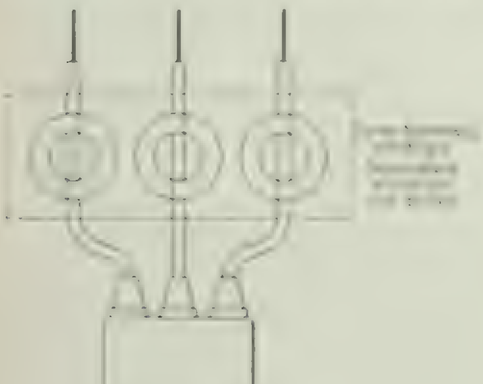
upset the balance of current between the two primary windings in each transformer, thus producing a magnetizing effect on the secondary windings and exciting the relays.

The transformers also serve a second function in case the fault occurs near one end of the split conductor, as at

[illegible]

[illegible]

[illegible]



[illegible] Circuit

[illegible]

[illegible]

[illegible] carried on common insulators and but lightly insulated one [illegible] Fig. 28 [illegible] ground the line will be cut out eve[illegible]

[illegible]

adjustment. The transformers can generally be built with bar primary windings, a construction which gives the maximum of simplicity and safety. The secondary windings are subjected to no forces except on the occurrence of a fault in the individual feeder which has to be protected, however severely the system may be disturbed.

It is difficult to connect up the apparatus incorrectly, but should the connections be crossed by mistake the switch will open immediately any attempt is made to put the feeder into service, and thus the mistake will be discovered.

Other forms of split conductor.—It is not essential that the conductor should be divided into equal sections. If one section be made smaller than the other, say reduced to a

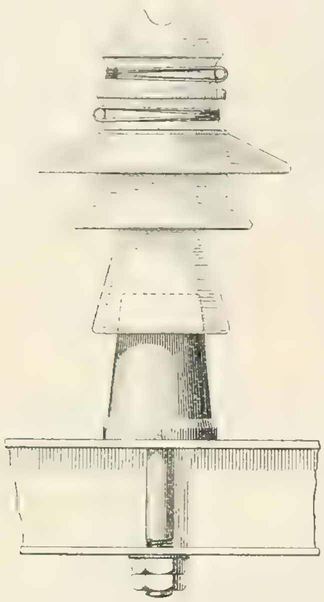


FIG. 29.—Details of Insulator shown in Fig. 28.

single wire, this wire may be carried always within the other portion which will surround it. Any fault to earth or between phases must occur on the outer portion ; thus it is unnecessary to provide for excess current in the inner portion.

We may now substitute a relay of the balanced type shown in Fig. 12. We connect the restraining coil to the inner wire and the operating coil to the outer conductor. The relay may be biased to an extent which fully covers all possible unbalancing, thus removing all occasion for balancing tests.

This arrangement is not quite so good as that above described, as the transformers cannot be constructed with bar primary windings, that for the fine wire requiring a multiple-turn primary. On small installations such as colliery and industrial plants where the conditions accompanying short-circuits are not so severe as they are on the large power supply schemes, this objection disappears, and advantage may be taken of the cheapening of the cable and the elimination of balancing. This applies equally where such plants receive supply from the power companies, as the severest short-circuit conditions are only met with near the generating stations.

The balancing problem now presents no difficulties, although in the experimental stage some were experienced. It is necessary to balance both the reactance and the resistance of the twin conductors as it is the vector difference which is operative. This requires no attention in overhead lines, and is successfully accomplished by the adoption of simple precautions in the manufacture of the cables.

The Ideal Combination of Apparatus.

Whilst a number of devices have now been considered, some of them by no means simple in design or application, it will be found that to meet all the ordinary and emergency requirements of electric supply there are now available a series of devices simple in character, well proven in service, and giving a degree of protection hitherto quite unattainable. The series is as follows:—

(*a*) For the protection of all closed feeder circuits—the split-conductor system.

(*b*) For the protection of all open-ended feeder circuits, including individual motor circuits, isolated transformers, rotary converters, and the like—the core-balancing system.

(*c*) For the protection of generators and banks of transformers—the circulating-current system.

The advantages of the above combination may be summarized as follows:—

(1) All the apparatus is simple in character.
(2) All the apparatus is self-contained and completely independent of that on other circuits.
(3) All the apparatus may be adjusted before installation.
(4) No feeder pilot-wires are required.
(5) The relays are all simple contact-making devices operating on excess current and are of the same character throughout. In many cases direct-acting trip coils can be substituted.
(6) The relays are not subjected to any forces until they are called upon to operate.
(7) None of the devices are affected by surges.
(8) None of the devices are affected by variations of voltage or of power factor.
(9) None of the devices are affected by faults occurring outside the sections that they control.
(10) All the devices will deal with faults between phases or to earth on systems with any number of phases.
(11) All the devices are instantaneous in operation.
(12) All the devices will operate at currents comparable with and generally materially less than the normal load current.
(13) If incorrect connections are made this will be discovered on the first trial run.

[illegible]

[illegible] United States is by continuous current. In such cases it has been found, owing to the effect of the synchronous [illegible] two or three years, they still use such apparatus. In this country in our industrial districts the development has been, and seems likely to be in the future, in the supply [illegible] by the author becomes apparent ; in fact, it is a[illegible] any particular form of apparatus such as the author has described should be adopted is not primarily a question of which is the cleverest device technically, it really [illegible] much deeper than that. It is not a question [illegible] y modified so as to pro- [illegible] of the actual protective apparatus selected. [illegible] attention to that general aspect of the problem [illegible]

[illegible] are mostly run in [illegible] we cannot take up [illegible] chronous [illegible] station. With [illegible] purely a question of the relation between the load current and the fault current, and the potential of the feeder at [illegible] whether the current shall flow back from the sub-station [illegible]

mentioned above. Perhaps, however, the author will correct me if I am wrong, or if he has any suggestion to make which will mitigate the trouble. I should particularly like him to give me his opinion as to the following arrangement where four parallel trunk mains are run between two generating stations; that is, practically an interconnecter consisting of four parallel trunk mains. I do not see why an arrangement consisting of a core-balancing transformer at each end of each of the four trunk mains operating in each case on an independent relay, supplemented by overload relays on each phase of each feeder in the ordinary way as a stand-by, should not be a satisfactory solution; it would be very simple, because the feeders are already equipped with overload relays, and the core-balancing transformers could be placed round the feeders without introducing any further element of weakness. It appears to me that where there are four feeders in parallel, no matter on what part of any of these feeders the fault may occur, there must always be three times the fault current through the sub-station relay on the faulty feeder that there is through the relays on any of the other three, which should sufficiently discriminate between them, the sub-station end of the faulty feeder only being disconnected. Directly this occurs, however, the generating-station end follows. Since the arrangement is absolutely reversible it does not matter which is the generating end and which is the sub-station end, the generating end at any instant being always understood to be the one from which energy is most likely to flow to the fault.

Mr. E. G. WATERS: I have investigated in a small way the subject of protective gear. My first attempt was the balancing of duplicate feeders.* I notice that although this subject is referred to in the paper one or two good points that have been evolved have not been mentioned. The diagram herewith (Fig. A) illustrates what I mean. The

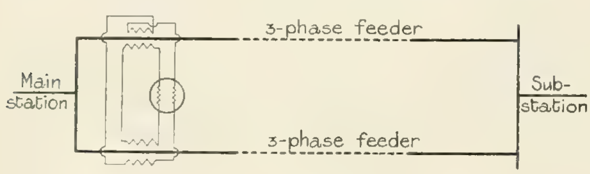


FIG. A.

core-balancing current transformers in each feeder are provided with two secondary windings. One pair are coupled together "in opposition" through one coil of a relay; the other "in assistance" through a second coil of the relay. These coils are arranged in a similar manner to those of a standard reverse-current relay, but as both coils are supplied from current transformers the action of the

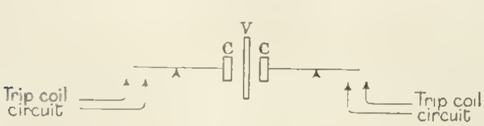


FIG. B.

relay is quite independent of voltage and power factor. Referring to the subject of reverse-current relays, Figs. B and C indicate diagrammatically an arrangement which renders the relays as nearly as possible independent of voltage. It will be seen that the pressure coil, V, and one current coil, C, form a simple reverse-power relay. Upon a reversal of current in coil C the second current coil really usurps the function of the pressure coil as soon as the slightest movement of the pivoted arm takes place. Stated briefly, the pressure coil gives one or other of the

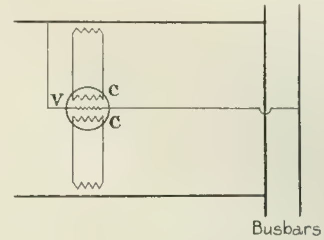


FIG. C.

current coils a bias to move, whereupon the interaction of the current coils completes the movement of the contact arm even though the voltage falls to zero. As regards the split-conductor system, the feature that I notice in connection with Fig. 23, as compared with Fig. 22, is the increased surface of the conductors. I should imagine that that would increase very considerably the capacity current and consequently the dielectric losses. If that is so, it puts the commercial use to a lower figure than the ordinary type shown in Fig. 22; but I should be glad if the author would refer to that point in his reply. In connection with special cables, I have also developed a system using the inductive effects of the leakage current in the cable to trip a relay through the medium of a separate conductor of small area in the main cable. Both these systems have been adopted on large supply systems, and I hope to be able at a later date to describe the results.

Mr. A. G. COLLIS: I suggest that the title of the paper, namely "Automatic Protection," admits of too wide an interpretation, and that the use of this term implies more than is expected. In this connection I notice that the author frequently uses the word "instantaneous," and uses it finally in his summary. The most positive relay which has come under my notice takes about 0·4 second to operate, and the time occupied by the gravity action of a switch is something like 0·6 second, hence we have a total time of one second for the period of operation of these two devices independently of any other consideration. We know that the rate of increase of the current is something of the order of 850,000 amperes per second, so that the circuit is not disconnected before an appreciable rise has taken place. Moreover, by that time destructive forces have appeared at the switch break. The existence of these forces was anticipated by Lord Kelvin, who referred* to the coreless vortices obtained by the motion of a solid through an inviscid incompressible fluid, and these forces are particularly interesting inasmuch as the nature of the arc and its formation changes with the type of contact used. I have taken out a series of experiments, and photographs showing the effects of the force distribution in the neighbourhood of the switch break are on the table. Electrical

* A full description was given in the *Electrician*, vol. 73, p. 270, 1914.

* Sir W. THOMSON. On the formation of coreless vortices by the motion of solid through an inviscid incompressible fluid. *Proceedings of the Royal Society*, vol. 42, p. 83, 1887.

[illegible] maximum load of any feeder to which it is connected; thus, assuming a distributing system in which the rating of the feeders varies from 500 amperes to 50 amperes, the larger-size resistance would have to be used, and hence [illegible] current that is determined by the larger (500 ampere) [illegible] introduction of resonance, where the capacity and [illegible] are such that the currents when both the inductance and the capacity are short-circuited are equal, with an introduction of the high harmonics nine times the fundamental. Is not split-core protection more suit- [illegible] this be easily done by means of the author's system of [illegible]

Mr. H. Brazil: One's first impression on reading the conclusions at the end of this paper is that all our troubles with regard to protecting a system from short-circuits and "earths" are at an end. When, however, one attempts to [illegible] doubts begin to arise, the final impression—at any rate in my own case—being one of bewilderment, and the final conclusion that the whole thing is somewhat complicated. I should like to make a few remarks on the split-conductor system, which is very novel and ingenious, but which has not hitherto been tried to any great extent. The author states that the special cable costs only slightly more than [illegible] be left, and I do not envy the [illegible] find such a fault. The [illegible] think [illegible] of the old system with overload devices [illegible] to put in a few words in its favour. [illegible] plicity, and although I [illegible] system having a very [illegible] systems described by the author is [illegible] where distribution is from sub-stations and [illegible] verters, I think the simpler form of overload [illegible] case of two parallel feeders with [illegible] to pass 800 amperes, [illegible] extreme end of the feeders [illegible] station and that the two cables carry eq[illegible] ing that under these circumstances with an earthing resistance of the iron-grid type having a positive temperature coefficient, this may be necessary, I would point out that [illegible] of the carbon-powder type could be des[illegible] 300 amperes when cold, which would be [illegible] most faults, and yet if a fault occurred at the end of the parallel feeders, the current would in a few seconds rise to 600 or 800 amperes, making certain that the cable [illegible] limit devices to prevent the [illegible] time limit a great help in maintaining continuity of supply.

Mr. Murphy.

Mr. L. Murphy: The author has described some excellent devices the value of which has been proved in practical working, and any technical criticism which may be made must therefore be directed to the operation of these devices under conditions that only very rarely occur. In most instances he has shown good reasons why the apparatus described will operate when a fault occurs, but unfortunately he has somewhat neglected the other important aspect of protection, that is, to show that the devices are not likely to operate under any conditions which occur on a healthy system. To have a healthy machine or cable disconnected by the wrong operation of a relay is possibly as bad an occurrence as when a relay fails to isolate faulty gear. In connection with this aspect of the question I consider that the circulating-current system of protection for generators is hardly as satisfactory as the use of properly-designed reverse-current relays. The accidental opening of a current-transformer secondary-circuit will cause a shut-down of the machine in the circulating-current scheme, and it should be remembered that the secondary connections are never so substantially made as to preclude entirely the possibility of this occurring. In addition, it appears that the circulating-current system affords no protection against reversal which may be due to any other cause than armature faults, such as failure of motive power or exciting current. There is also considerable extra complication involved in the subdivision of the generator neutral and in the provision of six instead of only three current transformers. I consider that the author has given an entirely false impression with regard to the behaviour of reverse-current relays. These instruments still form the most satisfactory and complete form of generator protection available, and may be used with confidence for open-ended duplicate-feeder protection if suitably rated, particularly if there is additional reactance connected in the lines. He also criticizes them because he affirms that they do not operate at any current when the voltage falls to zero, but it may interest him to know that at least in one case with which I am familiar the relay may readily be arranged to operate at zero voltage with five times the value of the operating current for normal voltage setting. Of course, all discriminating action then disappears, but the presence of the very least pressure on the potential terminals is sufficient to polarize the relay and considerably reduce the operating current, and I cannot imagine an instance where the voltage will be absolutely zero with any appreciable flow of current. Much, if not all, of the trouble arising from reverse-current relays operating on surges would disappear if users would adopt higher settings. There is often no possible objection to the use of settings of as much as 60 per cent or even greater amounts in certain instances, so long as the relays employed are truly of the reverse-current type of which the current settings are not appreciably affected by a severe drop of pressure. Probably much of the prejudice against the use of reverse-current relays is due to the many defective designs which were at first installed owing to a failure to grasp at once all the details which the problems of the protection of high-tension generators and feeders involved. Turning now to the question of the protection of parallel feeders and closed networks, it may be noted that the author recommends some system of balanced protection to meet all cases. It is noteworthy that he recommends a mechanical balance in the case of independent parallel lines, and magnetic balance for the twin-conductor system. Each of these methods has its disadvantages; the former must of necessity balance, not the currents, but the squares of the currents, and is therefore liable to be insensitive at light loads and over-sensitive at overloads, and it is impossible to state the out-of-balance current-setting either as a definite current or as a percentage excess of one current over the other. One reason for not using magnetic balancing for separate conductors is obviously the difficulty of obtaining perfect phase opposition in the two sections of the transformer primary winding; so apparently in order to get over this the split-conductor method has to be adopted, and the advantage of being able to run on one line if the other is shut down is thereby sacrificed. It may also be noted that, with split conductors, in the event of a fault to earth from both conductors simultaneously the current remains balanced and the system is absolutely unprotected. It is true that this condition is most highly improbable, particularly if the two conductors are arranged concentrically within a cable, but such a fault is quite possible on the overhead-line system shown in Figs. 28 and 29. I should also be interested to hear somewhat more definitely as to the additional cost of the twin-conductor cable. The author suggests that the excess is only slight, but if this is only a few per cent it may easily represent several thousand pounds on a large system. Incidentally it would appear that the working thickness of dielectric between the phases has to be considerably reduced if Figs. 22 and 23 are to the same scale throughout. Mr. Taylor has already criticized the author's remark that the split conductor is of universal application. Such is hardly the case since it involves duplicate conductors, and is not therefore applicable to systems already laid on the simple single-conductor plan. I consider a general solution should be one which may be applied to protect the cables of any closed-up network, however complicated, without first resorting to either running new cables or pilot wires in parallel, or the substitution of a special type of cable such as in the split-conductor system. Such protection may be obtained, I believe, on fundamental lines, using the effects of any fault to locate it and cut it out, in much the same way as the simple fuse may be made to protect a simple circuit. My suggestion is that the magnitude of the overload current and drop of voltage respectively should determine when and which cable requires disconnection. The cables may be connected in the most complicated network, and one relay would be necessary in each cable where it leaves a generating or sub-station. Fig. D herewith is not intended to show an actual mechanical arrangement; it is only supposed to illustrate the essential details which constitute such a relay collectively. On the right-hand side of the figure is a solenoid operated by a current. If the current exceeds a certain amount the solenoid core is drawn up and the beam on which it rests is free to operate. The latter would then be drawn up at a level speed by the weight W attached to a cord passing over the roller on the spindle of the eddy-current brake-disc above.* In rising the beam will move the contact B downwards, so

* It is not necessary to employ the eddy-current brake disc, as there are other means of obtaining a constant speed, and its use is merely suggested in the present instance.

[illegible]

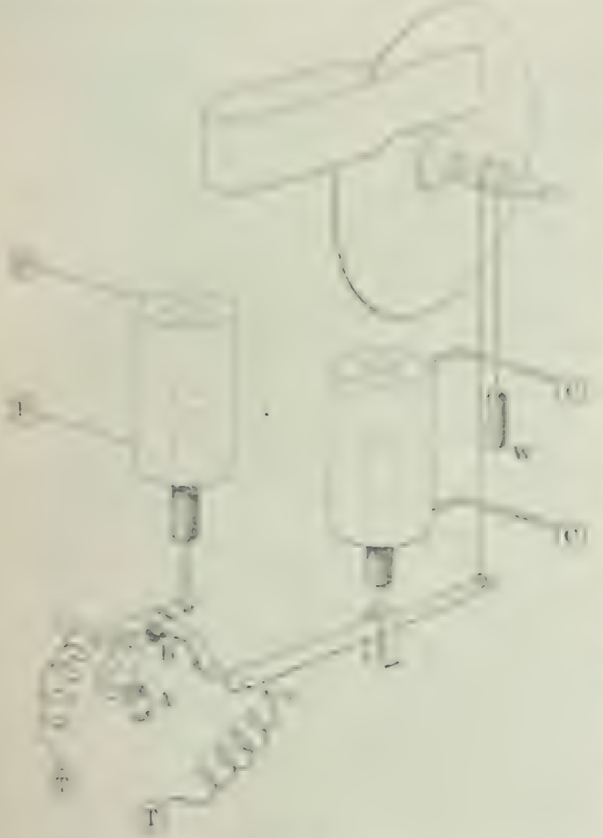


Fig. D.

[illegible] I think there would be no difficulty in obtaining [illegible] for a difference of voltage [illegible] per cent [illegible] I believe that any closed circuit could be protected in this way against both faults and overload, and the only conditions [illegible] are quite definitely connected, and will be the same for all relays on a given system. It is also interesting to note that the relays cannot operate until there is a dangerous overload on the circuit, after which

[illegible]

[illegible] to the practice [illegible] It is [illegible]

I have [illegible] the Merz-Price system, but where provision has not been [illegible] Merz-Price apparatus. Next to that, I know of nothing [illegible] true that where independent overload and reverse-current [illegible] load current of a circuit or less. Reversal does not occur in one of a pair of feeders at full load even under [illegible] meet the less favourable [illegible] fault current to reach [illegible] current, the relay associated with the unsound feeder carries what is in effect a reverse current immediately unbalancing occurs.

Mr. Taylor's [illegible] between four parallel [illegible] better done with core-balancing apparatus. The scheme is subject, however, to certain definite limitations, which are characteristic of proposals of the kind. Discrimination is obtained by utilizing the feature that the fault current [illegible]

Mr. Wedmore.

been shown that with parallel feeders the fault current must be more than twice the current setting of the individual switch, and approaches three times this figure. If, now, one feeder is out of service, there is little or no factor of safety to ensure that the sound feeders will not be disturbed by a fault not only in one of the parallel feeders but by any leak anywhere beyond those feeders. The scheme would be reasonably safe for a 5-feeder combination, but it must be recognized that there is a second element of uncertainty. The whole action depends upon the earthing resistance passing no more and no less than the assumed current within somewhat narrow limits.

Referring to the splitting of the switch contact on the split-conductor system, Mr. Taylor asked what results can be obtained without splitting the conductor. It is really a commercial problem; it is found that it actually pays to split the switch contact, which is quite readily done, rather than to build a transformer big enough to give the required results without splitting the conductor; *i.e.* the net cost of the transformer plus the switch is generally less where the switch contact is split than where it is not split, and that is the justification for splitting the switch-contact. Several installations have been made in which the switch contacts have not been split, and with quite satisfactory results.

Mr. Waters is a newcomer in the field of protective switchgear, and suffers under certain disadvantages on that account. He has made a very interesting series of relays which have certain novel and interesting constructional features. I regret that I was unable to include details of Mr. Waters' devices, or of any other individual relays in the paper, but I think Mr. Waters' inventions are actually covered by my remarks. Mr. Waters described a new system, which, as far as I can see, gives protection only from faults to earth, and it seems to me a pity to go so far as to build a special cable to obtain only that result.

Mr. Collis referred to the use of core-balancing apparatus in mining service, and asked whether the core-balancing device will really prevent the arc from appearing outside the cable. That is a matter which has been the subject of a good deal of experimenting. I may say that the tests made indicate that the employment of a sensitive leakage protective system on mining work certainly has the merit that the cables may be disconnected with a minimum of risk of the arc appearing outside the cable; in point of fact it is a difficult thing to get the arc to come outside the cable even where such apparatus is not employed.

In reply to Mr. Brazil, on the question of cost of the split-conductor system, I may say that the cost of the next best system, the Merz-Price, which is not so sensitive and has certain limitations, is practically the same as that of the split-conductor system. The cable joints have had to be the subject of special development; that development is quite interesting, in that the special joint which had been developed for split conductors is found to have the merit that it gives flexibility in the length of the cable. With regard to the insulation between the two halves of the split conductor, the word "light" is used in a relative sense. The illustrations show the actual facts. Mr. Brazil is quite right when he says that, under conditions of a "dead" short-circuit to earth on one core of a cable which is tied direct to the generating station, the full star voltage may appear between the two halves of the conductor, but I would point out that it is only a momentary condition, and that consequently a relatively small amount of insulation will readily withstand it. Moreover, on any cable not connected directly to the generating station busbars, that maximum voltage is never reached; nevertheless it has not yet been found to pay to develop two different makes of cable for the two positions. With regard to the employment of a resistance with a negative temperature coefficient for the earth connection, I am rather disappointed by the figures given. If on a 6,600-volt system we have to wait several seconds before the current reaches 800 amperes, one has to recognize that the system is being subjected to a fault taking 3,000 kw., which will probably shut down quite a large amount of the plant before the protective apparatus has a chance to operate. Much can be said, however, for such a resistance rated at 700 amperes when cold, as it ensures a larger factor of safety with a smaller initial current than is obtainable with units having a positive coëfficient.

Mr. Murphy is still optimistic as to the future of reverse-current relays, but I do not find any new feature or argument in his remarks on them. Relays such as he describes are not new. All the early reverse-current relays used to operate at no voltage, and it was not considered a merit. We are now obtaining more satisfactory service with the devices recommended than with any others that have been employed on any scale sufficient to justify conclusions, and that is being done on some of the largest systems in the country where severe faults are of frequent occurrence. Mr. Murphy has described a novel protective scheme, which I have not fully grasped. Others have endeavoured to find a solution on similar lines. The fundamental difficulty with apparatus of this kind is that it is impossible to predict what the current and voltage conditions will be. On site, each individual device can only be adjusted in a reliable manner by making actual short-circuit tests, and these adjustments require revision with each material alteration of the distribution system. It would appear also that the apparatus could only be adjusted to give correct operation on faults to earth, and on a short-circuit between phases all the relays would operate.

MANCHESTER LOCAL SECTION, 15 DECEMBER, 1914.

Mr. Welbourn.

Mr. B. WELBOURN: I am glad to see that the author bears in mind first and foremost the commercial aspect of the subject. On the first page he uses the expression "continuity of supply" three times, and that, I think, is the keynote of the whole paper. It describes automatic apparatus which has been introduced within the last 10 years and has made the distribution of power in bulk a commercial possibility. We ought not to discuss the paper without paying a tribute to the work which was done by Mr. Bernard Price about 10 years ago in the development of automatic apparatus for the disconnection of faulty feeders, generators, and transformers before the supply system could be affected sufficiently to cause synchronous machinery to fall out of step. The Merz-Price system of

[illegible] occurs, [illegible] upkeep amounts to. For the protection of over- [illegible] over the Merz-Price system, in that it [illegible] ties inseparable from supporting an [illegible] the route, and also from what is equivalent to an earthed conductor below the overhead line, such a conductor being liable to be fouled if one of the lines breaks. Moreover, the split-conductor system has this advantage, [illegible] in Fig. 33 is what is ordinarily recommended [illegible] cables, but there is another form, called the split-twin system, which is recommended for use where the cables are used in series with overhead lines. For this purpose the balance of the split-twin cable is sufficiently [illegible]

Mr. [illegible]: The question of protective devices is largely bound up with the question of earthing the neutral [illegible] and also with the amount of resistance [illegible] These questions should be [illegible]

[illegible] them, but now the [illegible] inferior to the [illegible] It seems to me that the system is exceedingly good, but [illegible] equality is very small and the ope[illegible] author has mentioned that the current trans[illegible] circuits, I agree with [illegible] siderable magnitude. The recommendations of the author [illegible] overload coils on two phases to protect against [illegible] namely (c), I [illegible]

Mr. Ferguson. transformers is at a disadvantage where the transformer is in a lock-up sub-station. When a transformer is switched into circuit the high initial magnetizing current is not balanced on the secondary side and causes the Merz-Price relays to operate. This means that if there is a stoppage and renewal of the supply the Merz-Price relays will operate, and an attendant has to go to the sub-station to re-set them. I do not know whether under such circumstances the author would recommend a time limit on these relays. This point is certainly a great disadvantage when the Merz-Price protective gear is used in a lock-up sub-station. If the gear is installed in a station where an attendant is always available I agree that there is no better system.

Mr. McKenzie. Mr. A. E. McKenzie: This paper supplements the information given by Messrs. Harlow and Faye-Hansen about four years ago in their paper on the same subject.* In Manchester 10 high-tension feeders were then being fitted with balanced protective gear, although at the time the neutral of the high-tension system was not earthed, the capacity current of the system being quite sufficient to operate balanced protective gear. It was not possible to use Merz-Price protective gear, as the high-tension feeders to the sub-stations had already been laid without pilot wires. I can thoroughly endorse all that the authors have said in regard to the advantages of balanced protective gear. When three current transformers have already been installed (and in most modern stations it will be found that such is the case) it really only needs a slight alteration to the wiring and an additional relay to have balanced protection as well as overload protection, as shown in Fig. 5. The first feeders that were fitted with balanced protective gear in Manchester had only two current transformers installed for overload protection. It was found to be much easier to install an additional transformer round the 3-core cable than to add a third transformer to balance with the existing two. One-half of the total number of high-tension feeders were protected in this manner. The remaining feeders (about 20) each had three current transformers, so the wiring was altered and an additional relay added, thus obtaining both overload and balanced protection. There has not been one fault, I think, that has not been satisfactorily dealt with by the balanced protective gear since it was installed. The worst fault during the last few years was in connection with a feeder protected by Merz-Price gear; it occurred in a kiosk on each side of which the feeder was protected by this apparatus. The fault occurred between the kiosk busbars, owing to the failure of an insulator. This feeder was also protected at the generating station by an overload relay with a time limit of one second, but the kiosk was badly damaged before the fault was cleared. I quite endorse all that Mr. Ferguson has said against providing time limits for balanced protective gear. We have always found it better to get rid of a fault as quickly as possible, and it seems to be a mistake to add a time limit to a device which has been initially installed to clear a fault immediately it occurs. In one part of his paper the author has advocated the use of balanced protective devices in series. I think that there is no necessity for this if one has a cable system which has been properly laid, as the number of faults that occur per annum does not warrant this. On the Manchester system there are over 150 miles of e.h.t. cable, and the number of faults which occur per annum is about six. I am sure it is better to risk cutting out the whole of one feeder on the rare occasions when a fault occurs than to have a number of these protective devices in series with time-limit devices at the generating station in order to obtain selective action. Messrs. Faye-Hansen and Harlow in their paper did not favour the protection of generators by Merz-Price gear alone. At that time, two of the large generators at Stuart-street station—and now every turbo-alternator and large generator in this station—were protected by Merz-Price gear with fuses in the secondary circuit, which blow only if the machine is kept on sustained short-circuit, or in the event of a fault occurring on the generator windings and the remaining generators sending current into the faulty machine in excess of its normal short-circuit current. The generators are thus protected against faults on their own windings, and also against faults which may occur on the main switchboard. Regarding the interlocking of parallel feeders, we have never been able to find a reverse relay that could be depended upon. Several feeders run into each of our most important sub-stations, and it has always been considered advisable to separate the high-tension busbars and make as many different sections as possible. The interlocking devices described by the author are novel to me, and if an opportunity occurs I should be very pleased to try them, especially the interlocked leakage relays. It is always advisable to disconnect temporarily the tripping circuits of switches at the generating station when "paralleling feeders in a sub-station provided with balanced protective apparatus, because, however accurately the switches are adjusted, one set of contacts is almost certain to make circuit a little before the others, in which case the protective gear, if not fitted with a time limit, will operate and probably cut out both feeders. It is advisable to have a small switch in the secondary circuit of the balanced protective gear on each feeder so that it can be used to open the circuit whilst feeders are being "paralleled." The ideal protective gear for a generator is, I think, to have Merz-Price balanced protection with fuses in the secondary, and in addition a device which will automatically cut off the generator field immediately the main switch opens. I do not quite understand why in Fig. 20 the author has put the transformer at the alternator end on one-half of the phase winding only. Of course satisfactory balance can be so obtained, but it seems to me it would be simpler to put the transformer on the neutral end of the winding outside the generator casing. It would not be possible on many machines to put the transformers in the position shown. The arrangement shown in Fig. 20 is that which has been decided upon for the protection of the main generators in the proposed new Barton station for Manchester. There will be no switchgear between the transformers and the machines. The alternators will generate at 6,600 volts with step-up transformers from 6,600 to 33,000 volts. Each generator and transformer will thus form one complete unit. Merz-Price balanced gear will be installed on the neutral ends of the generator windings and on the outgoing side of the e.h.t. transformers. In the event of a fault occurring either on a transformer or a generator

* *Journal I.E.E.*, vol. 46, p. 671, 1911.

[illegible]

[illegible] like a little more information. If the insulation between the inner and outer conductors is very slight, and there is a breakdown of the insulation, and the outer conductor is put to earth, it seems to me probable that the earthing might occur at the same time on the inner conductor and [illegible] I should like to ask the author whether any [illegible]nced from that cause. The same thing applies to two overhead lines. If they are earthed simultaneously, then the split-conductor system will fail to protect. The first account which I remember seeing of a device of this kind was, I think, by Mr. Andrews, in his book on "Electricity Control," 10 or [illegible] I should also like to support Mr. Welbourn's request for some figures as to the increase in cost from the use of this [illegible]

[illegible] that any consumer's fault, however severe, and whatever [illegible]

[illegible]

stake I think the question of [illegible] tective systems ought not really to be co[illegible]. We are [illegible] disasters may happen, and it is incum[illegible] to take steps [illegible]

[illegible] I refer, of course, to the Ferranti-Waters system. It seems [illegible]

[illegible] some details on which our op[illegible]

Mr. Faye-Hansen.

that it is impossible to go below something like 10 to 15 amperes with a series transformer of reasonable size, and I should like to know whether the author is able to use a much smaller current. Though the core-balancing principle is excellent, it ought in most cases to be utilized in connection with an overload device, as has been suggested by most speakers in the discussion, and as the Manchester Corporation is doing. Sometimes it may be quite satisfactory to have core-balancing protection only, but generally there ought to be a combination, such as is shown in Fig. 5. The biased protective relay shown in Fig. 12 is a very good idea. It will be appreciated by any engineer who has had to deal with the difficulty of getting a really good balance that can be relied upon under all conditions of overload and short-circuit. Of course it limits the sensitiveness to some extent, but it is a thoroughly sound, practical idea, which ought to be adopted very largely when balanced protective gear is used. Fig. 13 is very interesting to me. It is exactly what was described in the paper by Mr. Harlow and myself.* We pointed out at the time that, from the theoretical point of view, it will protect any parallel feeder or interconnector quite satisfactorily, but of course it depends upon pressure transformers and upon the voltage not falling absolutely to zero in the event of a breakdown. If it were not for these points it would be the best way of protecting parallel feeders and interconnectors and to ensure that under all circumstances the faulty cable, and that only, is disconnected. In Fig. 18 the author shows the secondary circuit of the Merz-Price gear earthed in two places. I think that is only an oversight, because even in transformer protection where the distance between those two points is small, there would be some risk of a potential difference existing between them and thus causing operation of the relays when this is not wanted. The arrangement illustrated in Fig. 20, of protecting transformers and alternators in series by having two parallel circuits in the alternator, is very interesting. It has one advantage over the system ordinarily used, and described by Mr. McKenzie, namely, it protects the alternator in case of breakdowns between different parts of the same phase of the machine, which the ordinary Merz-Price arrangement would not do. With the present method of construction of most alternators, that is not a very important point, and it can only be obtained by complications in the alternator design. Mr. McKenzie referred to a statement in the paper by Mr. Harlow and myself in regard to the use of Merz-Price gear for generators. As explained in our reply to the discussion on that paper, what we wanted to express was that the Merz-Price gear alone should not be used for protecting alternators; there should be something in addition. The arrangement used by the Manchester Corporation and described by Mr. McKenzie exactly meets that view, and against protection of that kind I have nothing to say. In Fig. 21 it would, as explained before, be entirely correct from a theoretical point of view to protect both ends of the parallel feeders and interconnectors with the so-called interlocked reverse-current relay shown in Fig. 13. I now come to the split-conductor protective system. It is certainly a very good one, and I believe that it will in the future be adopted more and more freely. When it was first brought out I had not much faith in it, but at that time the cables were on the twin system and were not as shown in Fig. 23, one core inside the other. On the twin system there is always a danger that both cores might break down at the same time and the same fault current might flow to earth from each core; whereas with the concentric cable, as now adopted, that is not possible. Apart from cost, the only disadvantage of the Merz-Price gear and the split-conductor arrangement for feeders is the small part of the system which cannot in a practical way be protected by it, such as sub-station busbars, etc. In this respect the core-balancing system in connection with overload is preferable, where it can be adopted without trouble; but no other system gives the freedom in the lay-out of the cable system that the Merz-Price and the split-conductor protective gears do.

* *Journal I.E.E.*, vol. 46, p. 671, 1911.

Mr. Wedmore.

Mr. E. B. WEDMORE (*in reply*): Members who have not had time to study the details in the body of the paper have been lead to believe that the schedule on the last page is a complete schedule of apparatus. This is not the case, and I did not mean to exclude overload devices, especially in conjunction with item (*b*). Moreover this item is generally inapplicable when the mid-point of the system is insulated. Earthing the mid-point has so recently been fully discussed that I have said very little about it in this paper.

The term "instantaneous" is used by relay designers to distinguish relays having no delaying device from those that possess one. We shall never have an instantaneous relay in any other sense. I believe Mr. Welbourn's figures represent what is practicable and what has been attained in the operation of relays and oil switches. It is quite practicable to obtain a core-balancing relay to operate in 1/20th of a second, but there is no occasion to do this.

The cost of the split-conductor system is at present comparable with that of the Merz-Price system, but in course of time it should be reduced, as inherently that system is cheaper than the Merz-Price system.

Mr. Ferguson objects to the use of the time-limit devices in conjunction with balanced gear, but advances no arguments against my specific recommendations in this connection. I have recommended the time-limit device as a means of obtaining discriminating action with the core-balancing leakage device. I have given the reasons for my recommendation quite fully in the paper. The leakage current on a system with the mid-point earthed through a resistance will represent only a temporary overload on the machines, and does not subject the system to severe shocks. If one wishes to discriminate between independent feeders and consumers' premises the time-limit core-balancing device on the individual feeder in conjunction with instantaneous core-balancing devices on the consumers' premises will give that result. Core-balancing apparatus is not necessarily delicate at all. In many cases we are using the same relays for core-balancing as are used for ordinary overload protection, and sometimes direct-acting trip coils.

In his remarks on the split-conductor system Mr. Ferguson refers to the questions of jointing the cables and balancing the cables. It is quite remarkable how well informed are engineers in all parts of this country upon a little difficulty that was experienced with the experimental installations. I can say quite frankly that when the first

[illegible]

and only one failure, which was due to no fault of the apparatus but to a constructional defect in the line. The circulating-current system of transformer protection has [illegible] The apparatus can be designed to avoid the difficulties that Mr. Ferguson anticipates.

I am very glad Mr. McKenzie introduced the subject of the automatic field switch. I became interested in this subject just after my paper was submitted, and we have since installed a considerable number of these switches. There is one feature worth mentioning in connection with the automatic field switch for making a machine "dead" [illegible] dependent upon the combined action of the automatic [illegible] The automatic field switch should not come out immediately the relay works, in case the main switch fails. On the other hand, it should not come out immediately the main switch opens, because that means that a machine cannot be taken off the busbars without breaking the field circuit. If the automatic field switch is made dependent upon the action of the relay plus the switch, I [illegible]

[illegible] one merit of the combination which I did not include in the paper. I should like to say in answer to what was perhaps a criticism, that the device is only intended to be applied where the armature is being already wound in two parallel portions. The device has the merit also that it [illegible]

[illegible] referred to the insulation between the two halves of the [illegible] insulation as "relatively slight." That ins[illegible] much less insulation between the two halves of the core [illegible] operation of the protective device.

[illegible] which Mr. Waters has introduced some novel and interesting features in relay design, of which I think we shall hear [illegible] cannot be inserted.

[illegible] with promising designs, that "if" would [illegible] the market by several manufacturers [illegible]

BIRMINGHAM LOCAL SECTION, 16 DECEMBER, 1914.

Mr. Taylor. Mr. A. M. TAYLOR: I should like to ask the author whether he sees any objection to the following method of protecting a group of four existing trunk feeders which are in parallel and adjoin two generating stations: Retain the present overload time-limit relays, remove reverse-current relays, and introduce at each end of each trunk feeder a core-balancing ring transformer. It seems to me that such an arrangement would be quite satisfactory under all conditions of supply, the core-balancing arrangement forming a quick disconnection from earth, and the overload arrangement acting as a stand-by in the event of a short-circuit between phases or of the failure of the core-balancing arrangement to operate. Where four feeders are in parallel, the current operating the core-balanced transformer on the faulty feeder will invariably be three times that of any of the three sound feeders. With reference to the split-conductor method of protecting new feeders, the good features of this arrangement are that it not only takes into account all the fault current proper, but also equally responds to short-circuits between phases. Of the two methods described for applying the split-conductor system, I greatly prefer that in which the oil contacts of the oil switch are split, provided this does not interfere with the efficiency of the switch for really serious faults. It also seems to me that the method introduces fewer elements of weakness into the split-conductor system in the way of transformers than does the other method, which might, however, be useful in certain cases. The author's interlocked overload method depends upon the joint effect of the load current and the fault current, and it is quite possible under certain conditions, which can be easily reproduced, that one of the sound feeders might be disconnected at the sub-station end instead of the faulty feeder. This, however, will only occur when the earth connection at the generating station is made through a very high resistance. At the same time, this is the condition that the author recommends.

Dr. Garrard. Dr. C. C. GARRARD: The various schemes which are described in the paper have each their very valuable and proper field of application, and when confined to such spheres of usefulness nothing can be said against them. I find myself, however, unable to agree with the author's general conclusion in which he tabulates three systems, the combination of which he designates as ideal and capable of meeting all the ordinary and emergency requirements of electricity supply. An ideal system should surely be a sufficient system. On the author's own showing, however, the combination suggested in this respect falls short of the ideal. Take for example the protection of generators on the circulating-current system shown in Fig. 17. This figure shows overload protection in addition to the Merz-Price gear, this overload protection being obtained by means of time-limit fuses. All the makers of Merz-Price gear agree that this system alone is not sufficient for the protection of generators, and these time-element fuses are invariably supplied. Now I had thought that the undesirability of overload protection on generators in a station where continuity of supply is of primary importance had been settled years ago. Such generator overload-releases will probably result in the alternators being shut down successively in the event of a heavy short-circuit. The circulating-current system only protects a generator against a breakdown to earth. A breakdown between phases or between windings is not dealt with, nor is an accident to the prime-mover. I also think some device is necessary which will trip the oil switch in the event of a mistake being made when synchronizing. A good reverse-power relay will deal with all these difficulties, and, for generator protection, I consider it is better than the Merz-Price system. Turning now to transformer protection, the circulating-current system is put forward as ideal. Again, however, it is insufficient. It is necessary to protect the transformer against sustained overload so that time-element overload protection is also required. The circulating-current system is excellent for guarding against a breakdown of the transformer to earth, but it must be supplemented by fuses or overload relays. In fact, the author in his ideal system leaves out overload protection altogether. I think he will be unable to persuade engineers in charge of plant to follow him in this course. I understand that Messrs. Reyrolle, who have had considerable experience with the Merz-Price and the split-conductor systems, recommend time-element overload protection on feeders in addition to its use on generators. I believe they also advocate inter-connector cables fitted with instantaneously-acting overload releases, so that in the event of a bad short-circuit the whole system is split up into a number of independent sections. It is, I think, also absolutely necessary to install overload protection to guard against such things as a short-circuit on a switchboard or the failure of an oil switch, neither of which are guarded against by the balanced system of protection. The point of view which I should take is that the balanced system is an excellent additional safeguard, the expense of which is warranted on large and important systems. It is a mistake, however, to maintain that it renders all other systems unnecessary. Referring again to transformer protection, I think it is impossible to protect transformers by instantaneously-acting trip coils in the way shown in Figs. 18 and 19. The reason of this is that, when switching in, abnormal magnetizing currents are experienced owing to the phase relationship between the residual magnetism and the electromotive-force wave at the instant of closing the switch. It is necessary to arrange for fuses as shunts to the tripping coils in order to get over this difficulty.* With reference to the split-conductor system, I believe I am correct in saying that the originators of this system now invariably use switches with split contacts. With cables of any length it is found necessary, if split-contact switches are not used, to employ abnormally-large current transformers if accidental tripping is to be avoided. The use of split-contact switches is found to be preferable. In any case the use of bar primary windings, as mentioned on page 168, would be impossible unless split switches were used. The author recommends the split-conductor system for closed feeder circuits. Hitherto, of course, the balanced-voltage Merz-Price system has held the field for such

* K. FAYE-HANSEN and G. HARLOW. Merz-Price protective gear and other discriminating apparatus for alternating-current circuits. *Journal I.E.E.*, vol. 46, p. 678, 1911.

[illegible] mentions, I [illegible]

[illegible] views on the question of neutral-point earthing, etc. I think that as far as feeder protective gear is concerned, [illegible] cent of the e.h.t. supply systems in this country. We [illegible] operated without any failure or trouble for some years. [illegible] account of more modern investigations, I shall condemn the feeder system as being insufficiently protected, and if so, whether the various kinds of gear described by the [illegible] can easily be dealt with, but I am hardly convinced that engineers controlling average-size systems carefully laid out under existing conditions have very much to fear, even if the cost of such schemes as are under discussion makes it commercially practicable. The sudden pressure-surges due to [illegible] all growing undertakings should at once receive careful attention in this respect. I cannot quite follow the author when he states on page 157 that the expenditure on cables [illegible]

[illegible] to, but will have to receive very careful [illegible]

[illegible] that in all the [illegible] this system of protection by leakage currents is [illegible] portant. Such machines must be capable of [illegible] on account of the [illegible] the possibility of failure [illegible] in most cases the fault will be one to earth instead of [illegible] limited by a neutral earthing resistance. The [illegible] this is that, first, the current that can flow [illegible]

[illegible]

about a marked change in the operation of the system, quite apart from any question of faults. Spare feeders are no longer kept in reserve, waiting for a working feeder to break down, but are run in parallel, and are therefore always available in the case of a working feeder being disconnected. I have known many instances in which working feeders have been inadvertently disconnected and the supply to consumers has not been interrupted because the second feeder could be and was being run in parallel with the first in conjunction with automatic protective devices. These devices therefore are important factors in assuring a continuity of supply to a consumer and in preventing synchronous machinery from being shut down temporarily, in which case the whole process of synchronizing has to be gone through. When consumers can exact a penalty of £5 a minute for discontinuity of supply, as in a case of which I know, this advantage of automatic protective devices is one of great moment. I do not agree with those who consider that pilot wires are unsatisfactory. I have laid and maintained very great lengths of such cables and I can speak highly of their freedom from trouble. The disadvantages of pilot wires are commercial and not technical. The use of pilot wires involves additional expenditure, but the split-conductor cable costs more than the ordinary cable. The factor deciding in many cases which is to be employed—a split conductor or a system involving a pilot wire—is whether the split-conductor cable costs more or less than the ordinary cable plus a pilot wire. One of the advantages of the core-balancing system is that, as far as I am aware, no royalties are payable. The system was in operation in America at least some three years before it was introduced into this country. There is another system not mentioned in the paper, and to which reference may be made as a matter of interest, namely, the Höchstadter, which is said to be extensively employed in Germany. To my mind it is a clumsy method and involves a considerable interference with the design of the cable. The system consists of wrapping each phase of the cable with a spiral conductor, which, however, is insulated from it. When a fault occurs the fault current is supposed to return to the power house by the spiral conductor and to operate the relays. In the early days of feeder protection by these automatic devices, Merz-Price and others, in many instances the relays operated from a cause which could not be ascertained. It was not known whether the relays operated when they should not have done or whether some unknown conditions in the cable brought about the action of the protective system. I should like to know whether in the present state of development the ratio of ascertained to unascertained causes of operation of the automatic protective devices has changed.

Mr. Groves. Mr. W. E. GROVES: Referring to the ring main shown in Fig. 1, it is a simple matter to protect the sections E F, F G, G H, and the author mentions that at each distribution point the circuits are independent and can be protected as such; the busbars, etc., are not, however, covered by his proposals. A comparatively short ring main may have something like a dozen works connected to it, and assuming that at each of these points there is an in-going and out-going switch connected to a busbar, the protection of these sections is of greater importance than the protection of the short lengths of cable between the individual works. As these interconnecting cables are far less vulnerable than the busbar portions of the ring, it seems unreasonable to cover the former and not the latter. It would appear that in dealing with ring mains the protection of the "tees" formed by the switch panels and busbars on consumers' works has not received the consideration that it merits.

Mr. Whitcher. Mr. J. WHITCHER (*communicated*): The engineer who constantly uses these devices has the more vital interest in them, and I should therefore like to emphasize some of the facts that ought for him to emerge from the discussion. First, there is the distinction between those systems that operate only on a leakage or faults to earth, and those that operate also on faults between phases. If a central-station engineer decides that he will rely solely on the former, he can and ought consistently to construct and organize his distributing system to ensure that a fault must be an earth fault before it can develop into a fault between phases. He can plan with this intention from the generator to the consumer's terminals. Moreover, on his existing system and plant he can investigate the statistics and probabilities of occurence of these two classes of faults, with the more or less certain result of confirming his opinion that the system will be sufficiently guarded by leakage devices. Now, if that be so, a new situation is created in his war against faults. The fault can be definitely limited in magnitude by neutral resistance. The various discriminating expedients may assume a new lease of life, when they deal only with leakage faults and are not subject to unlimited rushes of current. When, however, an engineer cannot safely ignore the possibility of phase-to-phase faults occurring, and these do not give rise to leakage effects until the disturbance is serious and widespread, or when his system is a single-phase or 2-phase one with an earthed leg, or is a 3-phase one with a solid neutral earth, or no earth at all, then it must now be agreed that he cannot rest satisfied but must venture further with contrivances such as duplex feeders, pilot wires, or split-conductors. Now it is easy to show a very close relation between these conceptions. They are derived from each other quite simply, and if the supply engineer recognize this, he will realize more clearly how either or all of them will fit into his distribution system, present and future. Balanced-current protection originated in 1903 in connection with duplicate feeder transmission, and pilot-wire protection for the case of a single feeder was its twin. It was clear that balanced-current devices gave perfect and instant discrimination on any "length" section of duplicate mains. The four switches controlling the ends of such a section would open with decision. The trouble arises from dissatisfaction with this condition. We are still anxious to add some refinement to prevent the opening of the two switches on the sound feeder of the pair. The valuable result first achieved was lost sight of in the desire to improve it; and the idea of the split-conductor has brought it out into the open again. For those engineers who have the old systems of duplicate mains the broad principle stands out, that these systems can be worked under split-conductor conditions, and that the more or less successful refinements of inter-locking relays, etc., can be applied to them so as to keep in the sound feeder of the pair. Failure of the latter system will but mean reversion to the former. For an absolutely

[illegible] this current [illegible] thus precluding the use of the porcelain-tube insulators. I would point out that the author's [illegible] the use of separate current transformers in each [illegible] peculiar to the split conductor ; and I therefore think it better to secure the balance in the current transformer ; [illegible] attendants cannot be trusted not to disturb protective [illegible] Separate current transformers ought therefore to be used for the latter.

Mr. [illegible] I have dealt with Mr. Taylor's remarks in my reply to the discussion in London.

Dr. [illegible] the end of the paper on the grounds that no mention is [illegible] details, including the use of such devices, are given in the body of the paper, and the concluding schedule is not intended to be a complete summary of details. The general function of overload devices has been fully dealt with, but I [illegible]

[illegible]

In reply to Mr. [illegible] the files of the Patent Office. [illegible] sooner we know about it the better. The [illegible]

Mr. [illegible] It will then be sufficient to protect the ring [illegible]

COAL AND ITS ECONOMICAL USE.

By P. S. THOMPSON, Associate Member.

(*Paper read before the* NEWCASTLE LOCAL SECTION, *at Middlesbrough*, 27 *March*, 1914.)

ABSTRACT.

According to the recent Royal Commission on Coal Supplies our coal reserves are 147,000 million tons or (as estimated by the International Geological Congress of 1910) 189,000 million tons—figures which suggest at the present rate of consumption a margin of 500 years.

Granted the necessity for economy, what are the means to be adopted towards this end?

By centralization of electric power supply consequent upon the development of the steam turbine much has been accomplished, but much more may be done without radical departure from present practice. Mr. Woodhouse in his address last year as Chairman of the Yorkshire Local Section* emphasized the necessity for co-operation between heat users whereby the surplus heat from one process might be used in another. A scheme of this kind is in successful operation on the North-East coast, electrical energy produced by means of waste heat from coke ovens and blast furnaces being distributed over a wide area. Into the question of the possible saving by the fuller application of electricity to haulage on railways and driving in factories, the author cannot here enter; and as to the waste of coal used for domestic purposes, Mr. Woodhouse suggested a partial remedy in low-temperature carbonization, which would allow of the recovery of the valuable products now lost, and yet leave a residue containing, say, 10 per cent of volatile matter.

Methods of economy, such as those here indicated would, in order to be thoroughly effective, have to be undertaken on a national scale; but once undertaken they would inevitably lead to what appears to be the ultimate solution of the problem—the almost universal use of electricity or gas, according to which of these agents would best fulfil the requirements of any particular case.

Coal may be regarded either as a source of certain valuable products, or primarily as a fuel without reference to its value in other respects. The first point of view is now becoming generally accepted as that tending towards true economy in the use of coal.

COAL AS A SOURCE OF PRODUCTS.

The primary compounds obtained by heating coal out of contact with air are distilled at a temperature not exceeding 930° F., but above this temperature secondary reactions take place. It follows therefore that not only the kind of coal but also its treatment must be carefully selected according to the products required. In gas manufacture, for instance, rapid carbonization at high temperature is required, but in the manufacture of coke the process is one of slow carbonization, the maximum temperature being maintained for some time after carbonization is complete. Carbonization primarily designed to recover hydrocarbons is carried out at a low temperature, which is not allowed to exceed that required to drive off the volatile matter. This method produces a comparatively small volume of gas of high calorific and illuminating value, but plenty of tar rich in light solvent oils, and coke containing sufficient volatile matter to permit of its smokeless combustion in the ordinary open grate.

In the production of metallurgical coke, however, the conditions are different; the temperatures are much higher and the primary products of distillation undergo secondary changes and simplification. The by-products of this process when carried out in recovery ovens are ammonia, benzol, and illuminating gas.

Ammonia.—There are several methods of ammonia recovery, but that attended by least loss of heat is the so-called "direct" method in which the gases are kept at a temperature sufficiently high to prevent any condensation of ammonia vapour. The tar vapour is washed out by a spray of hot tar and the ammonia is finally recovered as sulphate by treatment with sulphuric acid. One hundred tons of coal coked yield on an average one ton of sulphate of ammonia.

Benzol.—This is extracted by washing the gas with an oil—usually creosote oil—which has the property of absorbing benzol. The solvent oil is then subjected to distillation to expel the crude benzol, which is then rectified.

In the manufacture of gas one ton of coal carbonized produces one gallon of benzol, but in coke-oven practice, where the illuminating value of the gas does not enter into the question, one ton of coal carbonized will yield about three gallons of benzol.

Much has been said of the future of benzol as a motor fuel, but even if all the coal gas made were deprived of its benzol and if all coke were made in recovery ovens, it is doubtful whether the benzol thus obtained would wholly supply the demand. Further, as the changes necessary for such wholesale recovery of benzol would be of so drastic a nature, it is likely that benzol will still remain a by-product rather than become a primary object of coal distillation.

Illuminating gas.—Coke ovens with recovery plant are now becoming established as a source of illuminating gas for town consumption, more particularly in America and in Germany.

The rich gas produced during the first stages of carbonization forms the town supply, and the poorer gas of less illuminating value given off during the later stages is subjected to a benzol-recovery process. It is understood that the Middlesbrough Corporation are about to obtain a supply of town gas from coke ovens on some such plan by arrangement with a local firm of ironmasters.

* *Journal I.E.E.*, vol. 52, p. 30, 1914.

[illegible]

... in his price for such rest[illegible]

[illegible]

It is the amount of shale and dirt present in the coal which is responsible for variations in the calorific value, [illegible] value and the amount of external moisture ; further refinements would be left to a recognized fuel analyst should the day-to-day tests indicate any serious departure from standard quality. Calorific value is best determined [illegible] combustion being given up to a known volume of water in [illegible]

[illegible]

The following is an appoximate percentage analysis of a typical coal of this district :—

[illegible]

... depends upon t[illegible]

The theoretical value for the ma[illegible]

[illegible] figures give some idea of what temperatures to expect with reasonably efficient combustion.

[illegible] furnace is a heat-absorbing reaction.

The combustion of fuel is no longer looked upon as a [illegible] as important as it is obscure.

[illegible]

When raw fuel is fed into the furnace the following cycle of operations takes place: (*a*) Raising of temperature to the distillation point of the volatile matter; (*b*) the distillation of the volatile matter; (*c*) combustion of the volatile matter, now in the form of gas; (*d*) combustion of the fixed carbon. During (*a*) and (*b*) processes heat is absorbed; and during (*c*) and (*d*) heat is evolved.

These operations demand in the furnace: (1) A high initial ignition temperature (about 1,300° F.) and sufficient reserve of heat to maintain the same; (2) a sufficiency of air without excess; (3) a perfect admixture of air with the distilled hydrocarbons; (4) the avoidance of premature chilling of the products of combustion. These conditions are met by the provision of a large combustion chamber lined with refractory material, so constructed that the gases are not brought into contact with the heat-absorbing surfaces of the boiler before combustion is complete—otherwise the action of combustion is checked and smoke will result.

With perfect combustion the flaming gases are transparent, the furnace brickwork being clearly visible and of a whitish red colour. For proper inspection a tinted glass is necessary, the best being violet-blue, on looking through which, the burning gases and fuel assume a lavender-grey colour if combustion is perfect—if not, the flames will appear as streams of dark coloured gas as they do not give off radiant light of sufficient power to penetrate the glass. It appears that perfect combustion takes place at a temperature such as will produce rays capable of penetrating blue glass—this penetrative power is a measure of actinic power, which is in its turn an indication of intense chemical action. An inspection through blue glass is therefore to the practised eye a valuable means of ascertaining the state of affairs in the furnace.

It does not follow that complete combustion is necessarily economical, as there may be air present considerably in excess of the chemical minimum necessary to the process. This excess air having been raised to furnace temperature carries away a large amount of heat above that required to maintain the natural draught.

The draught or natural supply of air to the furnace is dependent upon the difference in weight of the column of gases inside the chimney stack and the weight of a corresponding column of air outside.

Draught is usually spoken of in terms of inches of water, and is indicated by the difference in level of a column of water in a U-tube, one end of which is connected to the boiler outlet flue just inside the damper, the other end being open to the atmosphere. To maintain a satisfactory difference in pressure, assuming reasonably airtight flues, the temperature of the exit gases from the boiler must be, say, 400° to 550° F., which accounts for roughly 11 per cent of the total heat value of the fuel.

In many cases this is too great a price to pay for a comparatively low draught which varies with atmospheric conditions, so that fans or other means of producing artificial draught have to be installed.

As a high efficiency can only be obtained by reducing the volume and temperature of the waste gases to the minimum consistent with proper combustion, it is necessary to keep these two factors under close observation.

The temperature of the exit gases depends not only upon the amount of excess air in the furnace but also upon the cleanliness of the boiler tubes or plates. These causes act, however, in opposite directions, since excess air lowers the temperature of the furnace and therefore of the exit gases, while dirty heating surfaces allow the gases to pass away uncooled.

The final temperature of the exit gases may therefore be the same on boilers of widely differing efficiencies, and therefore this temperature considered alone is not a safe guide to the economical working of the furnace. Other things being equal, however, the lower the temperature of the exit gases the higher the evaporative efficiency of the boiler.

A knowledge of the chemical composition of the waste gases affords a valuable aid to the control of combustion. Thus, when bituminous coal is burnt, the hydrogen of the hydrocarbon gases takes up oxygen to form water, and the theoretical amount of CO_2 is therefore less than in the case of the combustion of pure carbon.

The theoretical CO_2 obtainable varies from about 18 per cent to a little over 19 per cent, while 15 per cent is the best result obtainable in actual practice. A percentage of CO_2 below the maximum possible indicates that the gases are diluted with air, and the diminished CO_2 is the measure of this excess air. This excess air for the best practice is therefore $19/15 = 1{\cdot}25$ times, and that of good practice (12 per cent) is 1·6 times the theoretical.

It is difficult to obtain more than 12 per cent CO_2 without there being CO present, and as each 1 per cent CO present corresponds to a 2·2 per cent loss of the total heat value of the fuel it is unwise to allow the CO_2 to exceed the above amount. There are many types of apparatus on the market for taking continuous records of the amount of CO_2 present in the exit gases, but in the author's experience these are unreliable and have the serious defect of not taking cognizance of the presence of CO in the gases.

Since it is better practice to have 10 per cent CO_2 and no CO, than 14 per cent CO_2 and 2 per cent CO, the results of the CO_2 recorders should always be verified by taking samples at intervals and testing these by means of an Orsat set which allows of the determination of the amount of CO_2, O, and CO.

Heat Losses.

The heat value of the fuel in the furnaces is accounted for as follows:—

(1) The radiation loss which averages 5 to 7 per cent in modern boiler settings.

(2) The heat carried away in the exit gases, part of which in the case of natural draught installations must be regarded as the cost of the draught.

(3) The heat lost, or rather not evolved, owing to imperfect combustion.

(4) The loss due to unburnt carbon being carried away in ash and clinker—this works out at about 5 per cent for average practice.

(5) The heat absorbed by the heating surfaces of the boiler.

In order that item (5) should reach a maximum, the sum of items (2), (3), and (4) should be reduced to a minimum. Item (1) being a matter of construction is out of the control of the operator.

The control of items (2), (3), and (4) resolves itself into the adjustment of the air and fuel supply until the most

[illegible]

Item (3).—The following is an example of item (3) and [illegible]

[illegible] consumed carbon amounts to $1.8 + 0.68 = 0.085$ lb.

When 1 lb. carbon burns to CO, 14,646 B.Th.U. are produced

[illegible]

The difference is 10,131 B.Th.U.

[illegible]

Loss corresponding to 10 per cent CO_2 = 1,872 = 15.6 per cent.

[illegible]

The fuel is assumed to be a typical north-country coal [illegible]

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]
400° F.	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
Increase for 100° F.	[illegible]	[illegible]	[illegible]

DISCUSSION.

[illegible] and that if many of the by-[illegible]

Mr. Stedman

in the air is absorbed and heated up while the oxygen is doing work.

Mr. Lunn

Mr. J. R. P. LUNN: I am surprised that the author makes no reference to the use of gas in internal combustion engines instead of for raising steam. According to theory and test-bed results, the former should make more efficient use of the gas than the latter, but this does not appear to be confirmed under ordinary working conditions. I do not agree with the author that coal should be bought on a calorific-value basis. If coal is bought on such a basis, the rejection of deliveries which do not come up to the standard, or the reduction in payment for such deliveries, is very liable to irritate the coal owners or merchants, with the probable result that a margin is put on the prices charged for coal sold under such conditions in order to compensate for rejections or adjustments of price. The author appears to suggest that it is necessary to use a fan in order to work boiler plant under the most economical conditions, and I shall be very glad to have more information on this point. An induced-draught fan absorbs a considerable amount of power, and for a steady load it is questionable whether a good natural draught is not more economical. For heavy loads of comparatively short duration mechanical draught is no doubt more economical than natural draught.

Mr. Taylor.

Mr. H. M. TAYLOR: I think that there are still possibilities of profit in the clinker generation of steam. As regards the author's mention of the calorific value of the gas, in 1910 the standardization of gas for public supply in Middlesbrough was reduced by one standard candle, *i.e.* to 12 c.p. Then this year powers have been obtained to standardize the gas on thermic value instead of candle-power, namely 125 calories per cubic foot of gas. I think that CO_2 recorders are necessary in the test-room of a station, and they may be of great value to the superintendent of a large boiler-house, but they should not be placed in the charge of stokers.

Mr. Wright.

Mr. J. WRIGHT: I think there can be no doubt that the gasification of suitable coal is a step in the right direction if economy is to be looked for, and I think that the power stations of the future if not run in conjunction with a coke-oven plant will include a gas-producer plant, and will utilize the gas used to fire the boilers. It seems to me that the present moderate prices of sulphate of ammonia, etc., would justify the capital cost of such a plant. The author mentions on page 185 the rapid combustion of coal in the form of dust. I believe there is a future for this method of using coal, although it has not made great progress up to the present. Some years ago I assisted in carrying out some experiments in boiler firing with pulverized fuel, and the results obtained were not bad. The whole object of such an arrangement is of course to get each particle of dust floating in enough air to supply oxygen for burning it. Combustion following ignition is then quick and complete (sometimes too quick), leaving only dust particles of unburnt ash. It was, however, this unburnable ash that caused trouble, as it formed on the furnace walls in the form of a clinker which was quite impossible to be removed without damaging the brickwork, and it was owing to the heavy cost of brickwork repairs that the experiments were discontinued. When we had newly pulverized coal and the burner adjusted to give the proper quantity of air we found that the best brickwork which we could get would not stand the high temperatures. We had considerable trouble with the burner, as slight variations in the properties of air and coal caused a tendency for the flame to blow itself out. Our experience also showed that it did not pay to pulverize the coal and put it into stock, because the coal dust packs together into lumps. I believe there is a combined pulverizer and burner on the market in which the coal is pulverized and mixed with air in a single operation; this seems quite a good arrangement. The Bettington boiler and furnace has also been designed to burn such fuel, and I believe gives good results. While with the same firm I assisted in testing a coal-burning internal-combustion engine, and I mention this together with the experiment given above as being interesting from a coal-economy point of view. I believe this is one of the only attempts that has been made to utilize the coal direct in the engine cylinder, and from the results then obtained I am not surprised. The coal dust was fed into the combustion chamber through a series of valves. Here also trouble arose with the proportions of air and coal dust; it is quite easy to see that it is a very difficult thing to regulate coal in such a finely divided state, and governing is out of the question. This was not the worst trouble, however, as the engine would only run for a short time owing to the cylinder getting coated with easily volatilizable matter.

Mr. Longma

Mr. R. M. LONGMAN: The author has not mentioned peat and ignite. There are large stores of peat scattered all over the world which may be available, and it is a question of getting suitable means of utilizing them. In the *Electrical Review* of the 14 March, 1913, the use of lignite at a station in Rhenish Westphalia is referred to. With regard to the selection and testing of coal, sampling should be done regularly, and in the case of a large power station such tests should be made daily.

Mr. Greenw

Mr. D. E. GREENWOOD: With regard to the purchase of coal on a calorific-value basis, of course the colliery proprietors do not like it, but when coal is bought through a merchant who knows that a test is being made periodically on the coal supplied, a better quality of fuel is obtained. Any expense incurred through testing, therefore, is well repaid. The sampling of coal is really the most important item of all. Any good calorimeter will test similar samples to within an accuracy of 0·3 per cent. In coal-contract specifications there is generally a margin allowed of 2 per cent above or below the specified calorific value to allow for errors in sampling.

Mr. Brettelle

Mr. C. O. BRETTELLE: I am pleased to see that the author places little reliance on the CO_2 recorder, which seems to be a good servant but a bad master. If a stoker is told to keep the CO_2 up to a certain percentage, he will do so at the expense of everything else; nevertheless, I saw some time ago that it was even proposed to make a part of the stoker's wages depend upon the amount of CO_2 indicated. With regard to the question of draught, it has often occurred to me that there might be less trouble from air leakage with forced draught than with induced draught. With regard to what Mr. Lunn has said about the question of mechanical draught compared with natural draught, I do not know whether he took into consideration the difference in capital cost of the two schemes. That generally has an important bearing on the matter.

Mr. Wilkins.

Mr. S. WILKINSON: With regard to what Mr. Green-

[illegible]

Mr. W. H. Patchell: [illegible]

Mr. A. P. Maxwell: [illegible] in the distribution of the coal from the pits to the loco- [illegible] money may have to be spent by way of capital expenditure [illegible] an uneconomical one from a commercial point of view. [illegible] rarely that the capital expenditure is not justified by the economies to be effected. The author deals more particularly with the utilization of coal by burning it direct [illegible] its many drawbacks I fear it will have to be left out of the question where power production and its distribution is the principal purpose in view. The efficiency of turbines and of gas-fired boiler plant is continually improving, and [illegible] plant, with the object of providing gas for use under boilers? In this respect it seems to me that those who recommend the use of producer plant do not realize that the gas engine has not come up to expectations. In considering a scheme of this kind, the relative importance of the principal products and the by-products is to be [illegible] amount of ammonia, but it is the coke which is the chief item. Again, I have heard of plants being proposed with the object of getting the greatest quantity of benzol. That

[illegible] to go upon, but I believe a scheme of this kind would [illegible]

Mr. D. S. Thompson (in reply): [illegible] of carbon when burnt to CO, and to CO_2.

[illegible] when one considers that the cost of natural draught is of [illegible] is beyond question. I am glad to know that Mr. Brettelle is in agreement with this point of view.

With Mr. J. Wright I believe that there is a considerable [illegible] now approaching solution.

[illegible] sideration, but it would appear that the furnace temperatures for boilers might be rather unmanageable. At about [illegible]

Mr. Thompson.

ticularly with coal containing an appreciable amount of iron pyrites. Mr. Jackson in his recent paper* referred to this brickwork trouble.

Mr. Palmer's remarks open up a wide subject and one which would merit full discussion. It is, however, necessarily outside the scope of the present paper.

Mr. Marshall has admirably summarized the question of electric power production in conjunction with the gasification of coal. Hitherto the production of electric power has been in the nature of a by-product, and how far it can be made otherwise is a matter for very careful consideration. A decision is made more difficult owing to the comparative failure of the gas engine for use on large power systems. Gasification is an essential step in the economical utilization of coal, and it is unfortunate that it should be necessary to resort to steam as a medium of heat utilization, for, as Mr. Marshall points out, this means a heavy loss in efficiency. Whether it pays to gasify coal primarily for steam raising for turbine machinery is at present an open question.

* J. W. Jackson. Steam boiler-working in electrical power stations. *Journal I.E.E.*, vol. 52, p. 474, 1914.

INSTITUTION ANNOUNCEMENTS.

ANNUAL DINNER.

There will be no Annual Dinner of the Institution during the present session.

DIVISIONAL ENGINEERS—ROYAL NAVAL DIVISION.

The following letter has been received by the Institution :—

Copy.

Divisional Engineers, R.N.D.,
2, *The Downs, Dover Road,*
Walmer.

31 December, 1914

The Secretary,
The Institution of Electrical Engineers,
Victoria Embankment, W.C.

Dear Sir,

It has now been decided to form another Field Company of Engineers for this Division, and in view of the enormous help the Institution gave us previously in the recruiting of what is considered to be the best Divisional Engineers Unit formed since the outbreak of the war, I venture to hope that you may again help us in the raising of the additional Company authorized, as I am keenly desirous of having at least two sections of highly trained men.

It will interest you to know that nearly one hundred Commissions have been granted for men of this Unit since September last.

I therefore venture to suggest that you circularize likely men of your Institution who could then apply direct here, addressing their letters to Captain Harrison, Adjutant.

Hoping that you will be kind enough to let me hear from you in reply.

Yours faithfully,
(Sd.) G. H. Harrison,
Captain R.M.,
Adjutant.

It is understood that the rates of pay and the duties are the same as those of the Royal Engineers.

Applications from members of the Institution between the ages of 19 and 35 should be addressed to :—

Captain Harrison,
Adjutant,
Divisional Engineers, R.N.D.,
2, The Downs, Dover Road,
Walmer, Kent.

DISCUSSION ON "POWER PLANT TESTING."

YORKSHIRE LOCAL SECTION, [illegible] DECEMBER, [illegible]

[illegible] with the representatives of the firms which I considered could be relied upon to substantiate their figures, and [illegible] differently from most people, and that it was upon this [illegible] fact that careful acceptance trials were often [illegible] made that firms putting forward very low steam con- [illegible] ttled by a slight reduction in the purchase price [illegible] for a careful test to be made [illegible] firms who put forward reliable figures. At the [illegible] ating set running at a high load factor [illegible] leads to the question whether in [illegible] men are available for superintending the carrying out of

[illegible]

[illegible] two [illegible] have been forgotten. It seems to me, therefore, that there [illegible] method of testing, and consequently he is in a far better [illegible] well provided for in regard to meals.

[illegible] station staff, with the object of helping to maintain the [illegible] CO_2, draught, flue temperature, and water recorders, are [illegible] measurements. Boiler testing is really not only a matter [illegible] is all that is necessary for everyday working and to enable [illegible]

Mr. Clo... flue-gas analysis under the ordinary conditions of working. Unfortunately, these instruments require considerable looking after if their readings are to be reliable. In many power stations it is often difficult to measure the steam consumption of a generating set or the evaporation of a boiler without making alterations. I think it is a most important point in power-station design to see that any unit of plant can be tested under normal working conditions. If consideration is given to this point in the first instance, much trouble is afterwards saved. Many of us can probably recall instances where special arrangements had to be made in order that tests might be carried out on a plant, with the result that after the first official test little or no further testing was done. This also raises the point whether generators should be tested on a water-tank load or the ordinary supply load. In my opinion the latter will usually be sufficient. With regard to coal testing, I think the best method is to do regular sampling and approximate analysis, coupled with occasional firing tests on the boiler grates. The latter need not be an evaporation test but simply a test or observation to show the firing qualities of the coal, quantity of coal able to be burnt, draught, nature of clinker, etc. The author draws attention to the burning of known bad coals on separate furnaces, and while agreeing with this principle it is not always easy to carry out owing to this fuel having to be handled and kept separate from the other coals. This arrangement might be pursued further by burning the more inferior coals at times of light load and retaining the better coals for times of heavy load. The same difficulties would, however, arise with regard to bunkering, etc. I agree with the author's remarks as to the difficulty of burning coals having a large percentage of duff, and of the low efficiency that results. What is wanted with such coals is more agitation, and this is absent in stokers of the chain-grate type. A practical way of reducing the trouble is to wet the coal slightly, and this also assists in reducing the tendency to form clinker. With regard to the measuring of condenser circulating water by the thermal method, the dryness fraction of the steam entering the condenser must be taken into consideration in calculating the quantity of heat in the exhaust; if this point is overlooked considerable error will result. I should like to ask the author what is his practice in making such tests and how he arrives at the above figure. The dryness fraction can be approximately calculated from the temperature-entropy diagram and by assuming an adiabatic expansion of the steam. I have found this to give fairly reliable results; the calculated figure for the amount of circulating water can be roughly checked from the probable efficiency of the motor and pump. The author has also referred to the electrical method of testing condensers for leakage water; I take it he refers to the conductivity meter as made by Messrs. Evershed and Vignoles. In making such tests, however, great care must be taken to get accurate results, and tests must be made on both the condensate and the circulating water at the same time, as in tidal rivers and even with cooling towers the nature of the water is liable to vary. The electrical method, though useful in certain cases, has its limitations.

Mr. Morley. Mr. H. W. MORLEY: This paper appeals to me because for something like 30 years I have been interested in all kinds of steam testing, and the author's remarks largely confirm the results of my own observations. I find particularly that the personal element in testing is exceedingly important. Of about 100 observers with whom I have had to deal I have not had more than perhaps 10 who could be relied upon for any continuously careful testing. It seems to me that there is no doubt whatever that careful testing of all works plant should be made by the owners of that plant. These tests could not in the ordinary way be accurate within 3 or 4 per cent, but they would be useful in comparing the proportions of the various parts of the plant and in guiding the engineer in future extensions. Putting the argument in another way, it is quite easy to buy a good and efficient turbine and generator and to lose the advantage owing to the incorrect proportions of the boilers to that plant. Coming next to the question of contractors' acceptance tests, on close guarantees only those should carry out these tests who have spent a considerable time on expert testing and know how to convey instruments from one place to another successfully. I attach little importance to favouritism in the making of a test. It is said that the contractor will favour his own plant and that the buyer will tend to test the contractor's plant under the most stringent conditions. In connection with electrical instruments, the author's argument is one that I have never seen put so lucidly before, namely, that the idea is to reproduce on test the conditions which exist in the National Physical Laboratory. I should also like to confirm the results given on page 112, and to say that 10 per cent of CO_2 and 300° F. final temperature can be considered satisfactory. I also agree with the author that the only satisfactory way to test coal is to buy not less than 10 tons and test it in the boiler itself, for heat values obtained whether by analysis or in a bomb calorimeter are not altogether satisfactory. The tendency at present is to reduce the area of the surface condenser below that which is practically safe. Results obtained with a dirty condenser are much inferior to those obtained with a clean one, so that if the surface of the condenser is too small it entails more frequent cleaning than if a larger area had been used. The author said that the figure of 0·3 in. of mercury had not been criticized. I should consider it an excellent result, but to give 0·4 in. would, I think, be more satisfactory. In conclusion, I would repeat that I think all power plant of whatever kind and however small should be tested and continuous records kept. Where this has been done and the graphic method has been used both in testing and in the daily tests, I have found that this method will quickly show errors on the one hand, and unsatisfactory readings on the other, forming at the same time an additional check on the final figures taken.

Mr. Y... Mr. H. E. YERBURY: I think that the author's view in regard to the period of from 8 to 10 years for the complete obsolescence of boilers and turbo-generators will in most cases be looked upon as ideal, and will not be seriously acted upon in practice. Happy is he whose undertaking is in such a good financial position that he can replace out of revenue plant 8 to 10 years old. Of course the class of station and conditions of working influence very largely such a proposition. Whilst I admit that the bonus and penalty clause has become a leading feature in specifications, the payment, or enforcement as

[illegible] used on all classes of stokers. After 15 years' experience [illegible] to a specification calling for the same steam consumption after 12 months' working as was obtained on the original test. Others are willing to guarantee that the decrease in [illegible] 3 per cent after each year, then I heartily agree with him that plants should be looked upon as obsolete after the suggested period of from 8 to 10 years.

Mr. J. H. SHAW: With reference to Mr. Yerbury's remarks about scrapping plant in eight years, I should like to state that our last 2,000 kw. of load above 9,000 kw. comes on during November and goes off early in January, and that during this time it generates only [illegible] generates a kw.-hour at a cost of about 0·1d. I estimate that the peak-load plant supplies a unit for considerably less than 0·3d., making a difference of £80 in a year. The last boiler is coupled up about the 13th November and taken out about the 30th January; it runs for 45½ hours in that time, so that a difference of 2 per cent in efficiency makes a difference of [illegible] a year. In a big power supply [illegible] tested again.

Mr. W. [illegible] annum for interest and other costs of capital, instead of the author's figure of £24,000, the value would then be more like £3,000, or about one-eighth of that mentioned in the paper. I should like to lay stress on the point that it is quite as important to know how the [illegible] that inspection is quite as important as testing. I should like to ask what range of error the author has found to be [illegible] sion of the fluid on the surface of the therm[illegible]. I should like to know how much that effect was, as I [illegible]

The figure would be useful for reference, as gas velocities are likely to be greatly increased in the future, the limit apparently being reached in the Bonecourt boiler, where the gas velocity exceeds the combustion propagation rate. In any specification it ought to be clearly stated what the tests will be and who is to pay for them, or what proportion of the cost is to be borne by each party. If we propose to work with absolute certainty to anything like the figures mentioned in the paper the tests will prove expensive.

Mr. R. N. CAMPION : I also have looked into the point made by Mr. Burnand about a 7,500 kw. plant working with a 50 per cent load factor, and I agree with the figure deduced by him. It seems to me that fixed guarantees and penalties are very difficult things to manage, because from 80 per cent to 90 per cent of the cost of the plant must be paid before these tests can be begun, and then, as various speakers have said, there is a difficulty about arranging a compromise if the results do not agree with the figures in the tender. I think it would be a good thing to get these allowances standardized. There is a question which I should like to ask the author in connection with the damping of the coal. I have found that by damping slack we get something like 2½ per cent less ash than we do with dry coal. We also certainly think that it burns better, and as we supply our own water we do not pay for the slack being washed by the colliery people. With regard to that other point of the author's as to a boiler evaporation from 30,000 to 18,000 lb., I have had the same experience in another way. When I have about a five-eighths load on the boiler if I want to increase it by another eighth I find it is half an hour before I can get steam up. The steam pressure will drop 30 lb. and there is a big blanketing effect—although the fires are thick and without holes, and the draught right—and I have not so far been able to overcome this disadvantage with the chain-grate stoker. In connection with the testing of instruments and returning them to the National Physical Laboratory—this did not take place at the station with which I am connected, but it occurred a little time ago in a fairly big works. They were having a test made on rotary converters and the commercial instruments which were supplied with the switchboard differed by as much as 4 to 5 per cent from the test instruments. As the test instruments brought up the test to about 94 per cent efficiency the engineer said he did not like that figure at all, and so both sets of instruments were sent back to the National Physical Laboratory. Now I understand that both these sets of instruments had been declared to be correct. What was the engineer to make of that? The author asks for some particulars to be filled in on cooling towers. I find that the temperature of the air is the chief governing factor of the temperature of my cooling towers. It seems to regulate everything.

Mr. W. HOLEHOUSE : I am giving particular attention at present to the cooling tower, the difficulty of which is that it has no standard specification, and therefore in testing plant it is necessary for attention to be given to this point so that the different parts of the plant are somewhat more in line with the installation which is put down. Undoubtedly a scheme can be devised whereby a boiler, generator, and auxiliaries can run "on a line" so as to form a basis of a station for testing purposes. A cooling tower generally performs a certain duty, viz. that of reducing the temperature of so many gallons of water, and this bears no proportion to the load that can be put on it. Therefore, the test on a cooler does not give the total leakage on the station, although as it is the last part of the power station it ought to give some idea of how the plant in general is running. The author quotes figures assuming 70 lb. of water per lb. of steam, but in practice I have seldom come across such a proportion. May I ask him to state whether it is possible in putting down a power plant to stipulate the maximum power that can be afforded for driving the auxiliaries. In this way we can arrive at a maximum quantity of water which can be circulated through the condensers, and over the cooling towers. Then whatever load be put on to the turbine, the temperature of that quantity of water will alter, thus giving for light loads a very much better vacuum on the turbine. I think that this would prove more profitable to the station than would fixing an upper limit of temperature obtained from a fixed vacuum.

Mr. W. M. SELVEY (*in reply*): Mr. Roles has put the case for accurate testing in a very clear way. Though personally I should always have been in favour of making measurements in the most accurate way possible, I should not have thought it worth while bringing the matter before the Institution had it not been for the growing popularity of the bonus and penalty clause, which is really only a side issue of a much larger idea in our modern business life, namely "payment on results." Put in another way; is the reward to the inventor, designer, or manufacturer to be simply so much per cent on works costs, or is it to be in proportion to the benefit resulting to the community? I have felt that in engineering it is difficult to bring home to the buyer the relative merits of the different proposals made to him, and in analysing the situation I saw that in some cases, such as that of power plant, it ought to be possible to reduce a few of these merits to reliable figures. Business people have shown their willingness to pay on results, and the best manufacturers have also shown that they are willing to substantiate their guarantees. It would therefore seem that the third link in the chain was the technical assessor, who, to be of any real service, must necessarily have the confidence of all parties. That the heads of our large power enterprises are fast becoming purely business men needs no better proof than my quotation from Mr. Roles' address, which I used in reply to the London discussion. I think that such a tendency is inevitable, not only because of the size of the business, but also because of the action of committees; which, consisting of business men, are always bringing the business point of view to the front and discussing it with their engineer, or perhaps I ought to say their engineer manager. This results in the latter being less and less free to devote time to the technical side of the undertaking, and calls for more and better paid technical assistance.

I am glad to have the support of Mr. Roles in the monetary value of efficiency. With a lower load factor than I have taken, and for a machine of about half the size, he estimates the value of 1 lb. per kw.-hour as £5,000. Moreover, he says that recent quotations showed a difference of 1½ lb. of steam per kw.-hour, which is surprising. There are really only two types of turbo-alternators generally put forward, and I am convinced that

[illegible]

could be sold exactly as if the machine was not being [illegible] a few valves in order to put a set on test. We had a few [illegible] at liberty at the time. Testing never gave us any particular trouble when these men were available.

After the acceptance test has been done thoroughly, and then routine tests occasionally, by always watching recording instruments the state of the plant can easily be gauged. I left recording instruments purposely out of the [illegible] tests. The more reliable recording instruments we can get the better it is, but we want to be certain about the constancy of their inspection, and secondly that they are so arranged that if desired the engineer is in a position to check them himself one against the other. Thus the weigh-bridge could be used at least once a year to check the water-recording instruments, but should itself be regularly inspected, cleaned, and stamped.

[illegible] balance we have the only method of arriving at what the dryness fraction really is. From the known heat input is subtracted all the out-goings of mechanical work, whether

[illegible]

the exhausted air, I put this forward as about the limit [illegible]

[illegible] ston at Manchester.[3] There I sug[illegible] 10 years' time; but it is a dangerous matter to [illegible] has been [illegible] and penalty" clause, Mr. Yerbury's rem[illegible] cases have not come within my experience. Perhaps there were disputes on other matters connected with these cases. [illegible] flue gases was ever attained, but I think 8 per cent might [illegible]

[illegible] due to [illegible]

[illegible]

Mr. Selvey. details. With the reaction type of turbine much of the loss can be recovered by a moderate amount of periodic re-blading at the high-pressure end. With the impulse type any damage to blades, generally accidental in all cases, is a rather more difficult matter to deal with. Good cases are, however, on record with both types where a well-designed and well-run machine has gone for years without any signs of deterioration.

In reply to Mr. Shaw, I have said elsewhere that after eight years the plant is not scrapped. It is peak-load plant, and his facts are the best confirmation of what I meant. Far from scrapping plant in the North, I do not think that there is any apparatus, except perhaps some very small generating sets taken over from other companies, which is not in a position to do excellent work if required, but such plant is never in a position to prejudice the running costs. Every big turbine that is added to Bradford will, however, minimize the dependence on that small amount of peak-load plant. I can quite believe that Mr. Shaw has been in earnest about his testing, after hearing Mr. Roles say that contractors tell him they can always get through their tests everywhere else but at Bradford, which city when one looks up records has been the training ground of several successful municipal engineers. The specialist will always be glad of all the assistance that he can obtain from the station staff. By the expression "back of the boiler" should be understood the uptake or downtake through which the flue gases leave the boiler. It is indifferent to the heat balance where the leakage occurs; the only thing that matters is how much heat does it carry away.

In reply to Mr. Campion, I think the running hours given would not be remarkable for a good modern turbine, even as an operation point. Mr. Campion also suggested that there is a difficulty about the completion of the bargain made over a "bonus" or "penalty" clause. If this is so in many cases, surely a legal clause can be specially drawn to deal with it. I am perfectly certain that there are manufacturers who could be depended upon to the very last penny, if there were no other points at issue. The allowances must be settled in the specification, and as they may be up or down, the contractor takes the risk if he makes them inaccurate. To damp coal certainly makes it burn more freely. I have made some careful measurements on the point, and obtained about 1 per cent more CO_2 with a damped coal. Very little damping is, however, required, and it can be so easily overdone that it is a dangerous practice to recommend. The only reason that I can suggest for it is that it may cause a larger volume of radiant flame. Mr. Campion touches on a weakness of the induced-draft chain-grate stoker. To raise steam quickly, what is wanted is a very much higher speed of grate. To thicken the fire is no use without localized forced draught. Interesting developments are now going on in this direction. Mr. Campion's story about the instruments which differed on test and not at the calibration is the best case of which I have heard in support of my practice of drawing encouragement from the fact that we can almost invariably get 3-phase meters corrected by their calibration figures to agree to 2 or 3 parts in a 1,000 on site, and on full-load and long tests to agree often more closely. The difficulty is to reproduce the calibration conditions. A steam meter is a very difficult problem. A simple Pitot tube can only be an approximate indicator, no doubt very useful but not for acceptance tests. Mr. Hadley's paper* showed what hard thinking and clever construction was necessary in order to evolve a satisfactory air meter. The steam meter which I believe is also being studied in the same connection is a still more difficult problem. Mr. Selvey.

I am glad that Mr. Burnand has brought forward the money question, as I hoped that the discussion would indicate what would be a fair basis for a valuation of the efficiency. It seems that it depends not so much on the machine as on what is to be made of it, and hence the bigger the machine the still larger in proportion should be the value attached to efficiency. Even then it is not so simple, since the buyer's conditions will have changed after the machine has been running a year or so and he is considering his next extension. So in many cases the initiative may be taken by the contractor, who may himself suggest the risk that he is prepared to accept. In the matter of settling how the efficiency is to be obtained, there is even more benefit to be gained by looking into such questions when drawing up the specification than in testing after the money has been spent, but I am somewhat diffident in suggesting that this is also a question for the specialist.

In answer to Mr. Holehouse, what we know as the "unit system" or as he says plant "on a line" is undoubtedly one of the finest possible aids to a complete knowledge of power-plant performance. There are, however, very few stations where this idea has been carried out. The amount of heat to be dissipated in a cooler is undoubtedly a measure of the "inefficiency" of a station for a given number of units generated. As regards the quantity of cooling water, I think that the amounts will rise to 70 times the condensed steam, principally because attention is much more focussed on the condenser than on the cooler. The large quantity of water employed gives a high condensation rate, due to its high velocity through the tubes, and it enables the exposed surface to be reduced. I think there will never be any return to amounts as low as 50 times, which would probably need a 3- or 4-pass condenser in order to maintain modern reputations. The larger the size of the turbine the more likely is the quantity to be on the high side. This therefore gives the conditions for modern cooling towers, all of which must perforce deal with water at about 95° F. and reduce its temperature to 80° F., this drop of 15° F. being entirely settled by the ratio of the amount of circulating water to the condensed steam and corresponding in this case to about 65 times. These figures apply to the full-load conditions. The mean temperature of 80° F. will vary between 75° F. in winter to about 85° F. in summer, the top temperature varying just a little more in either direction, due to the effect of vacuum on the economy of the turbine. This still gives a margin of 6·5° F. from the steam temperature corresponding to a vacuum of 2 in. of mercury absolute (28 in.) which I have indicated as a likely aim for future big sets.

* A. E. Hadley. Power supply on the Rand. *Journal I.E.E.* vol. 51, p. 2, 1913.

NEWCASTLE LOCAL SECTION, AT MIDDLESBROUGH, [illegible] DECEMBER, [illegible]

[illegible] engines, but although the [illegible] self and resources for the production of more economical [illegible] engines that are cheap rather then economical. There [illegible] of the gains which inevitably accrue from the careful [illegible] as an illustration of the capital value of steam economy. I am aware that the figures given are only illustrative, but I [illegible] this represents a capital value of £3,000 on the [illegible] The answer [illegible] money in hand, and is, in any case, considerably less than £3,000. Another point to which I should like to refer is the very great advance that has been recently made in the [illegible]

[illegible] general lines set out in the paper have [illegible] a test boiler has much to [illegible] In view of the degree [illegible] that he [illegible] ally expect [illegible] glad if he would describe the form of inst[illegible] I agree with his remarks on the question [illegible] where salt water is being used, I [illegible] I have tried both, and the latter is far from satisfactory. [illegible] thermal method of measuring large quantities of cooling [illegible]

Mr. Longman. Mr. R. M. LONGMAN: I quite agree with the author that current and pressure transformers and instruments for alternating-current testing should all be carefully calibrated together and only the proper instruments connected to the various instrument transformers. The accuracy of many instrument transformers is nullified by the habit of fixing too many instruments to them. Potential transformers especially should only be very lightly loaded, and it is also strongly advisable that efficiency tests should be made at unity power factor, as any phase-angle error on either current or pressure transformers is thereby rendered negligible. The phase angle becomes of considerable importance for tests which are made at low power factor. Some tests recently made on a potential transformer of a well-known make with the coils of two integrating meters connected to it showed a phase angle of rather more than half a degree. This angle on tests at 0·5 power factor would make a difference of about 2 per cent. This emphasizes the necessity of knowing the load and the nature of the load on any current or pressure transformer. Of course, this can be measured or calculated and allowed for, but very often it is omitted. My own experience of contractors' instruments, etc., is that these have invariably been incorrect and against the contractors. A point in connection with shunts for continuous-current instruments either for integrating meters or ammeters is the necessity for plenty of metal in the connecting ends of the shunt and that connections should be made to it symmetrically so as to avoid stream-line effects in the shunt, thereby in some cases making a difference of 1 per cent or more. I think that the author's remarks concerning the slackness of college-trained men apply equally well or rather better to premium pupils. It is a question of keenness and true perception of the requirements.

Mr. Selvey. Mr. W. M. SELVEY (*in reply*): In reply to Mr. Hall-Brown in defence of my plea for greater accuracy in the testing of large prime-movers, I would suggest that the change from testing at the maker's works to testing on site caused by growth in the size of generating sets has really called for a slight advance in practice, and particularly for making provision in station design for periodic testing. In marine work even more emphasis is placed on reliability than in power-station work, since generally no spares can be carried, and the lack of ability to keep running will under certain circumstances mean the total loss of the ship. As long as there is supposed to be a conflict between efficiency and reliability, so long will improvements in efficiency be received with suspicion; though this attitude is breaking down as shown by the increasing number of Diesel-engine-driven boats now in commission. I have already dealt with* the question of the 8 to 10 years' equated life, which as Mr. Hammond subsequently pointed out is practically the same as the 15 years' full life. The question of accurate measurements as applied to condenser design has certainly had a marked effect during the last five years, having thrown into relief points which before were almost unsuspected.

In reply to Mr. Johnson Wright, may I take it he has noted a gradual improvement in the way acceptance tests are being conducted. These are receiving close attention at the hands of the purchasers of large sets, and in the shadow of this larger question the power taken by the

* See page 143.

auxiliaries, now quite considerable, is also being carefully investigated. As regards the question of the difficult coals, this could certainly be partly solved by the travelling shoot introduced at Hackney, which enables a supply to be taken from any bunker without much additional labour. I think that this scheme will be of great advantage if used for distributing extra good "nuts" to the boilers over the peak load. As regards a correction for scale in a boiler, I am perhaps somewhat prejudiced in preferring a "milk" scale on the back end tubes of a boiler. The front tubes of course work best when quite clean. With a multi-pass boiler this amount of scale will hardly affect the efficiency. With the old type of Lancashire boiler, which had a small surface, it would affect the final temperature appreciably. Mr. Selvey.

In regard to the use of the thermal method as against the Venturi meter, my point is not a strong one. What one wishes to know really is what is the mean temperature of the circulating water between its inlet and outlet. The effect of varying quantities of water on this mean temperature is small when the total rise is between 12° F. and 17° F., and is well defined. If used for testing the efficiency of a pump the method is much less direct than the Venturi meter method, which is then preferable. If, however, this means leaving the meter in circuit continuously, the increase in power is an appreciable amount of the total power taken by a low-lift pump. Hence I would prefer to test the pump at the maker's works with nozzles or V-notches if high accuracy seems desirable. Nevertheless, very close agreement has been obtained between the results on site by the thermal method and those given by the manufacturer's curves. As regards the question of signalling, I have stated what I have been led to by my own experience, and I have found many points in its favour.

Mr. Longman's remarks confirm those made by Mr. Fawssett,* and I am glad to have this confirmation of what I have said, as many members are strongly of the opinion that the steam consumption should be specified for the power factor on which the machine will be generally run. I still fail to see how we can get far astray in purchasing a machine which complies with the contract in giving a certain efficiency on unity power factor and a certain temperature rise on the required lagging power factor. If an attempt is made to cut down the iron and copper in the machine by using excessive ventilation, this ventilation will appear as a windage loss on the unity power factor test. In any case it would be well with any electrical machinery to satisfy one's self in regard to the relative volumes of active iron and copper in competing machines. Mr. Longman confirms the reasons for my desiring to test at unity power factor for the sake of instrumental accuracy. His experience vindicates the contractor as regards his disinterestedness, but suggests other thoughts. He joins with me in drawing attention to the need for accuracy in continuous-current shunts.

In conclusion, with regard to college graduates, Mr. Longman's experience is common to many of us who have had to depend on them. What I said was kindly meant, as a spur for increased keenness in the future. They have shown in other directions that they have the capability when the keenness is there, so that what is wanted now is, as Mr. Longman says, perception of the requirements.

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MEMBERS ON MILITARY SERVICE

(cont.)

Name	Corps, etc.	Rank
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
Harrison, Sir R., [illegible]	[illegible]	[illegible]
Haslam, S. B.	[illegible]	[illegible]
[illegible]	[illegible]	Able Seaman
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	Colonel
Hopkinson, Prof. B., F.R.S	Cambridge University O.T.C.	[illegible]
Howard, M. L.	Royal Engineers (T.F. Reserve)	Lieutenant
[illegible]	[illegible]	[illegible]
Leigh, F. A. C.	Western Signal Service, R.E.	Lieut.-Col
Le Rossignol, A. E.	London Electrical Engineers, R.E.	Lieut.-Col
Lewis, D. D. W.	1st Field Ambulance, Welsh Army Corps	Officer Commanding
[illegible]	[illegible]	Lieut.-Col.
Loos, A. E.	[illegible]	[illegible]
[illegible]	[illegible]	2nd Lieut.
[illegible]	[illegible]	2nd Lieut.
[illegible]	[illegible]	Corporal
[illegible]	[illegible]	Captain
[illegible]	Royal Engineers	Captain
O'Meara, W. A. J., C.M.G.	[illegible]	Major
[illegible]	Anti-Aircraft Corps (R.N.V.R.)	Able Seaman
[illegible]	Anti-Aircraft Corps (R.N.V.R.)	Able Seaman
[illegible]	[illegible]	Lieutenant
[illegible]	Anti-Aircraft Corps (R.N.V.R.)	Able Seaman
Roose, F. O. J.	[illegible]	Lieutenant
[illegible]	Royal Engineers	Maj.-General
[illegible]	Royal Engineers	Captain
Seligmann-Lui, G.	[illegible]	Lieut.-Col.
Sparks, H. C.	[illegible]	2nd Lieut.
[illegible]	Army Service Corps	Lieutenant
[illegible]	Royal Engineers	Captain
[illegible]	Director of Works	Brig.-General

Name	Corps, etc.	Rank
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

Name	Corps, etc.	Rank
Allingham, G. C.	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
Amberton, R.	[illegible]	[illegible]
Andrews, H. G.	[illegible]	[illegible]
Angwin, A. S.	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
Baldwin, H. R.	[illegible]	[illegible]
Battye, B. C.	[illegible]	[illegible]
Benson, H. K.	[illegible]	[illegible]
Binyon, B.	[illegible]	[illegible]
[illegible]	[illegible]	2nd Lieut.
[illegible]	[illegible]	[illegible]
Boxall, G. F.	[illegible]	Sapper
Boyd, W. B.	[illegible]	[illegible]
Bradwell, G.	[illegible]	[illegible]
Brandreth, W. E.	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
Broad, R. A.	[illegible]	[illegible]
Brown, G. J. L.	[illegible]	[illegible]
Brown, H.	Royal Engineers	[illegible]
[illegible]	[illegible]	[illegible]
Brown, W.	[illegible]	[illegible]
Brown, W. F.	[illegible]	[illegible]
Bruce-Kingsmill, J.	[illegible]	Lieut.-Col
Buckton, W. W.	[illegible]	[illegible]
Bullough, A. W.	[illegible]	Private
Bunn, W.	London Electrical Engineers R.E.	[illegible]
Campbell, C. M.	[illegible]	[illegible]
Carey-Thomas, H.	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
Chapple, F. J.	North Midland R.G.A.	[illegible]
Church, H.	[illegible]	[illegible]
Clark, R. W.	[illegible]	[illegible]
Clarke, F. C.	[illegible] R.E.	[illegible]
Clunas, J. F.	[illegible]	[illegible]
Collins, D. S.	[illegible]	[illegible]
Connan, J. C.	[illegible] chinery	[illegible]

Associate Members—*continued.*

Name.	*Corps, etc.*	*Rank.*
Cope, H. A.	London Electrical Engineers, R.E.	Lieutenant
Corney, H.	Royal Engineers	Sergeant
Cresswell, H. G. B.	London Signal Service, R.E.	Lieutenant
Crossley, C. E.	6th Notts and Derby Regt.	Private
Cunliffe, J. G.	18th Manchester Regt.	2nd Lieut.
Cunliffe, R. G.	Royal Garrison Artillery	2nd Lieut.
Davidson, A. E.	Royal Engineers	Captain
Davidson, C. H.	1st Northumbrian Brigade, R.F.A.	Actg. Bombardier
Davies, L. H.	14th Royal Warwickshire Regt.	Private
Davis, V. O. I.	Royal Engineers	2nd Lieut.
Davison, H. J. G.	18th Royal Fusiliers	Private
Dickinson, A. J.	Southern Signal Service, R.E.	Major
Digby, W. P.	London Electrical Engineers, R.E.	Lieutenant
Dillon, T. F.	Divisional Engineers, R.N.D.	Sapper
Dobson, W.	Royal Naval Reserve	Eng. Commr.
Dodds, J. W.	Northern Cyclist Battalion (T.F.)	Lieutenant
Dubbin, J.	Herts Yeomanry	Sergeant
Dumjohn, F. P.	London Signal Service, R.E.	Sergeant
Dutch, E. J.	2nd King Edward's Horse	Trooper
Edger, H. A.	Divisional Engineers, R.N.D.	Sapper
Elwin, E. P.	Divisional Engineers, R.N.D.	Sapper
Emmott, H.	Royal Army Medical Corps	Sergeant
Ewer, G. G.	7th Essex Regt.	Captain
Ferrier, S. K.	Divisional Engineers, R.N.D.	Sapper
Foster, F. W.	5th Royal Warwickshire Regt. (Reserve)	Lieutenant
Frank, R. A.	7th Liverpool Regt. (Reserve)	Sergeant
Franks, H. W.	Army Service Corps	2nd Lieut.
Fraser, A. R.	London Electrical Engineers, R.E.	Sergeant
Fraser, G. G.	5th Cameron Highlanders	Private
Friend, R. H.	Honourable Artillery Company	Private
Frost, P. B.	Royal Engineers	Sapper
Fuller, W. P.	Divisional Engineers, R.N.D.	Sapper
Gates, A. E. H.	Westminster Dragoons Yeomanry	Corporal
Geoghegan, F. W.	R.N.V.R.	Lieutenant
Gibson, J. S.	Royal Naval Division	Ordinary seaman
Gilbert, J.	6th Manchester Regt.	Private
Goulden, C. H.	Royal Garrison Artillery	2nd Lieut.
Grace, C. B.	Kent (Fortress) R.E.	Captain
Graty, T. R.	Royal Engineers	Sapper
Grierson, R.	Divisional Engineers, R.N.D.	Lieutenant
Grover, E. E.	14th Northumberland Fusiliers	Lieutenant
Gundry, W. L. D.	5th Devonshire Regt.	Lieutenant
Hann, C. S.	Public Schools Batt., R.N.D.	Ordinary Seaman
Hardie, C. C. A.	Royal Engineers	Lieutenant
Harris, L.	2nd King Edward's Horse	Gunner
Harrison, H. M.	Westminster Dragoons Yeomanry	Trooper
Hart, H. M.	Honourable Artillery Company	Gunner
Henrici, E. O.	Royal Engineers	Captain
Herron, G. F.	Royal Naval Air Service	Lieutenant
Higgins, C.	London Divisional R.E.	Lieutenant
Hill, F. A.	London Electrical Engineers, R.E.	Sergt.-Major

Associate Members—*continued.*

Name.	*Corps, etc.*	*Rank.*
Hills, R.	6th Notts & Derby Regt.	Captain
Hipwell, L. W.	3rd Royal West Surrey Regt.	2nd Lieut.
Hodson, W.	10th Royal Sussex Regt.	Private
Hogarth, L. B.	11th Border Regt.	Lieutenant
Holland, H. N.	Army Service Corps	2nd Lieut.
Hollington, A. J.	1st Railway Batt. 4th Queen's	Private
Holroyd, H. C.	Hants (Fortress) R.E.	2nd Lieut.
Hough, S. J.	Oundle School O.T.C.	2nd Lieut.
Hoyle, E.	Honourable Artillery Company	Corporal
Humphery, S. W.	London Signal Service, R.E.	Major
Hunstone, W. H.	Divisional Engineers, R.N.D.	Sapper
Hunter, E. B.	London Electrical Engineers, R.E.	Lieutenant
Hurlbatt, E. S.	7th Manchester Regt. (1st Reserve)	2nd Lieut.
Hutton, J. C.	6th South Staffordshire Regt.	Corporal
Iles, F. A.	Royal Engineers	Major
Jackson, E. W.	St. John Ambulance Brigade	Sergeant
Jackson, L. E. S.	Inns of Court O.T.C.	Private
Johnson, A. L.	London Electrical Engineers, R.E.	Sergeant
Kay, E. W.	Divisional Engineers, R.N.D.	Sapper
Kaye, G. W. C.	London Electrical Engineers, R.E.	Captain
Kidd, G. W.	Royal Navy	Eng. Lieut.
Kinder, H. F. A.	Royal Engineers	2nd Lieut.
Kirkby, H. M.	1st London Scottish	Sergt.-Major
Kirkpatrick, W. D.	R.N.V.R.	
Lamb, L.	West Lancs. Divisional R.E.	Lieutenant
Law, J. W.	Glamorgan (Fortress) R.E.	Lieutenant
Lawson, F. A.	19th Royal Fusiliers	Private
Lefeaux, E.	Kent (Fortress) R.E.	Captain
Le Feuvre, C. G.	Army Service Corps	Private
Lefroy, H. P. T.	Royal Engineers	Captain
Levin, A. E.	London Electrical Engineers, R.E.	Captain
Lloyd, N. V.	6th Manchester Regt.	Private
Lyell, J. C.	Anti-Aircraft Corps (R.N.V.R.)	Able Seaman
McCarthy, A. J. P.	Royal Engineers	Sapper
McNaughton, A. G. L.	2nd Canadian Artillery Brigade	Major
Mallinson, G. G.	Lancashire and Cheshire R.G.A.	Captain
Manners-Smith, J. A.	16th Middlesex Regt.	Private
Marsh, H. H. S.	2nd London Divisional R.E.	Major
Martin, D.	5th Cameronians	Col.-Sergt.
Massie, I. W.	Royal Engineers	2nd Lieut.
Masters, F. H.	London Electrical Engineers, R.E.	Captain
Mathews, S.	London Electrical Engineers, R.E.	2nd Lieut.
Maxwell, K. G.	6th Manchester Regt. (1st Reserve)	Captain
Mayes, A. E.	8th Hampshire Regt.	Major
Mead, W.	Warwickshire Rifle Corps	Private
Merrett, W. H.	London Electrical Engineers, R.E.	Captain
Middleton, E.	London Electrical Engineers, R.E.	Sapper
Miller, N.	Divisional Engineers, R.N.D.	Warrant Officer
Milliken, R. C.	London Electrical Engineers, R.E.	2nd Lieut.

Associate Members—continued.

Name.	Corps, &c.	Rank.
[illegible]	[illegible] Royal Lancaster Regt.	Lieutenant
[illegible]	Royal Naval Air Service	Lieutenant
[illegible]	[illegible] Royal Scots Fusiliers	2nd Lieut.
Monkhouse, S. E.	Tyne Electrical Engineers, R.E.	Lieutenant
Moore, B. J.	Royal Flying Corps	[illegible]
[illegible]	[illegible] Royal Fusiliers	[illegible]
[illegible]	Divisional Engineers, R.N.D.	[illegible]
Mountain, K. A.	Tyne Electrical Engineers, R.E.	Lieutenant
Mousley, J. H.	East Lancashire R.E.	[illegible]
[illegible]	London Electrical Engineers, R.E.	Lieutenant
[illegible]	[illegible] Royal Fusiliers	Corporal
Murray, James H.	Divisional Engineers, R.N.D.	[illegible]
[illegible]	R.N.V.R.	Sub-Lieut.
Napier, F. D.	Anti-Aircraft Corps (R.N.V.R.)	Able Seaman
[illegible]	Royal Naval Air Service	[illegible] Officer
[illegible]	[illegible] West Yorkshire Regt.	2nd Lieut.
[illegible]	East Lancashire R.E.	2nd Lieut.
[illegible]	Divisional Engineers, R.N.D.	Sapper
[illegible]	[illegible] Welsh [illegible] Brigade, R.F.A.	2nd Lieut.
[illegible]	[illegible] Engineers, R.E.	[illegible]
[illegible]	[illegible]	Corporal
[illegible]	Argyll & Sutherland Highlanders	2nd Lieut.
[illegible]	Divisional Engineers, R.N.D.	[illegible]
[illegible]	[illegible] Yeomanry	[illegible]
[illegible]	Royal Engineers	[illegible]
[illegible]	[illegible] Yeomanry	[illegible]
Phillips, J. H. S.	London Electrical Engineers, R.E.	Major
[illegible]	[illegible] Royal Fusiliers	Private
[illegible]	Royal Navy	Lieut.-Comr.
[illegible]	Divisional Engineers, R.N.D.	Lance-Corpl.
[illegible]	Royal Scots Fusiliers	2nd Lieut.
[illegible]	Divisional Engineers, R.N.D.	Sapper
[illegible]	Lancashire (Fortress) R.E.	Captain
[illegible]	Tyne Electrical Engineers, R.E.	Lieutenant
Reed, H. K.	London Electrical Engineers, R.E.	Sapper
Rich, T.	London Electrical Engineers, R.E.	[illegible]
[illegible]	Divisional Engineers, R.N.D.	Lance-Corpl.
[illegible]	Anti-Aircraft Corps (R.N.V.R.)	Able Seaman
[illegible]	Western Signal Service, R.E.	Major
[illegible]	Royal Navy	[illegible] Instructor
[illegible]	Royal Garrison Artillery	2nd Lieut.
[illegible]	Tyne Electrical Engineers, R.E.	Lieutenant
[illegible]	London Electrical Engineers, R.E.	Sapper
Rye, A. N.	Royal Guernsey Engineers	2nd Lieut.
Sanders, H. R.	London Electrical Engineers, R.E.	Sapper
[illegible]	Army Service Corps	2nd Lieut.
[illegible]	5th South Lancashire Regt.	Captain
Scott, J.	Mechanical Transport Corps [illegible]	Driver
Scrivener, R.	12th Royal Fusiliers	Lance-Corpl.

Associate Members—continued.

Name.	Corps, &c.	Rank.
Shaw, F. B.	Royal Naval Air Service	Lieutenant
[illegible]	[illegible]	[illegible]
[illegible]	[illegible] Highlanders	[illegible]
[illegible]	Royal Navy	[illegible]
[illegible]	[illegible]	[illegible]
Smith, A. P.	[illegible]	[illegible]
Smith, F. A.	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	Divisional Engineers, R.N.D.	[illegible]
[illegible]	Anti-Aircraft Corps (R.N.V.R.)	Able Seaman
[illegible]	[illegible] R.E.	[illegible]
Summers, L. F.	[illegible]	[illegible]
[illegible]	Divisional Engineers, R.N.D.	Corporal
[illegible]	[illegible] O.T.C.	[illegible]
[illegible] G. S.	17th Northumberland Fusiliers	[illegible]
Taylor, E. J.	[illegible]	[illegible]
[illegible]	Royal Navy	[illegible]
[illegible]	[illegible] R.E.	[illegible]
[illegible]	R.N.V.R.	[illegible]
Timmis, F. W.	[illegible] Artillery	2nd Lieut.
[illegible]	Royal Naval Air Service	[illegible]
[illegible]	[illegible] Engineers	[illegible]
[illegible]	[illegible]	Seaman
[illegible]	Divisional Engineers, R.N.D.	[illegible]
Turner, H. E.	East Riding R.G.A.	[illegible]
[illegible]	[illegible] R.E.	[illegible]
Utting, S.	[illegible]	[illegible]
Vincent, J. D. A.	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible] Electrical Engineers, R.E.	[illegible]
[illegible]	[illegible] East Surrey Regt.	[illegible]
[illegible] H.E.	London Electrical Engineers, R.E.	[illegible]
[illegible]	Royal Engineers	[illegible]
[illegible]	[illegible] Yeomanry	[illegible]
[illegible]	Artists Rifles	[illegible]
White, J. D.	R.N.V.R.	[illegible]
Whitney, W.	Divisional Engineers, R.N.D.	[illegible]
Wightman, O. N.	East Riding (Fortress) R.E.	[illegible]
Williams, E.	London Electrical Engineers, R.E.	[illegible]
Williamson, G. E. E.	Divisional Engineers, R.N.D.	[illegible]
Wilson, W. S.	Durham (Fortress) R.E.	Lieutenant
Wood, A. L.	15th Lancashire Fusiliers	[illegible]
Wood, E. L.	[illegible]	[illegible]
Woodward, E. H. E.	4th Gloucestershire Regt. [illegible]	[illegible]
Wray, T. H. R.	Royal Naval Division	[illegible]
Wright, F. T.	[illegible]	[illegible]
Young, C. R. M.	Durham R.G.A.	[illegible]

Associates.

Name.	Corps, &c.	Rank.
Bishop, W. J.	[illegible] Royal West Surrey Regt.	[illegible]
[illegible]	[illegible]	[illegible]
Clark, R. C. G.	[illegible] Light Infantry	[illegible]
Coutts, F.	[illegible] Black Watch	[illegible]
[illegible]	[illegible]	[illegible]
Davis, H. E.	Attached to Central Force [illegible]	[illegible]
Dennison, H. A.	[illegible]	[illegible]

Associates—*continued.*

Name.	*Corps, etc.*	*Rank.*
Ditmas, F. I. L.	Railway Transport Dept.	Staff Capt.
Doig, A. M.	6th Manchester Regt.	Private
Downes, H. L.	8th Liverpool Regt.	Lieutenant
Gardiner, A.	Royal Engineers	Major
Goody, H. E.	10th Royal Fusiliers	Private
Greenwood, H.	Anti-Aircraft Corps (R.N.V.R.)	Able Seaman
Hoskyns, O. P. L.	Queen's Westminster Rifles	Captain
Hughman, R. W.	9th Middlesex Regt.	Lieutenant
Johnson, W. L.	5th Durham Light Infantry (Reserve)	Lieut.-Col.
McClymont, R. A.	Royal Artillery	Captain
MacDonnell, A.C.	Royal Engineers	Colonel
McDougall, P.W.	Anti-Aircraft Corps (R.N.V.R.)	Able Seaman
Madge, R. G.	London Electrical Engineers, R.E.	2nd Lieut.
Marco, P. H.	13th York & Lancaster Regt.	Lieutenant
Miller, C. W.	6th Manchester Regt.	Lance-Corpl.
Morgan, J. G. Y. D.	Royal Navy	Lieutenant
Norman, Sir H., M.P.	British Red Cross	Commissioner
Northey, P. W.	Mechanical Transport	Lieutenant
Ogilvie, A. M., C.B.	Royal Engineers (T.F.)	Colonel
Pilkington, S.	4th Leicestershire Regt.	Lieutenant
Prance, H. W.	3rd City of London Regt. (1st Reserve)	Major
Punter, J. W.	Kent (Fortress) R.E.	Captain
Selby Bigge, D.L.	Northumberland Yeomanry	Major
Slorach, J. W.	6th Cameronians	Lieutenant
Tyler, H. E.	Royal Engineers	Colonel
Von Roemer, C.W.	Royal Field Artillery	Lieutenant
Wells, C. G.	Royal Engineers	2nd Lieut.
Wheeler, O.	South Midland R.A.M.C.	Private

Graduates.

Andrews, W. F.	London Electrical Engineers, R.E.	Sergeant
Applebee, G. A.	London Electrical Engineers, R.E.	Qmr.-Sergt.
Beamish, F. S.	14th Royal Warwickshire Regt.	Private
Bowater, T. D. B.	Westminster Dragoons Yeomanry	Lieutenant
Bowers, E. G.	9th Highland Light Infantry (Reserve)	Private
Brazier, C. C. H.	H.M. Hospital Ship No. 6	5th Engineer
Brown, H. A.	11th Cameronians	2nd Lieut.
Browne, W. S.	London Electrical Engineers, R.E.	Sapper
Burnett, F. E.	London Electrical Engineers, R.E.	Sapper
Campbell, Sir J. A. C., Bart.	3rd Scottish Horse	2nd Lieut.
Chandler, A. F. N.	Army Service Corps	Private
Douglas, A.	Divisional Engineers, R.N.D.	Sapper
Eardley-Wilmot, G. H.	9th Devonshire Regt.	2nd Lieut.
Girdlestone, H.	Yorkshire Dragoons Yeomanry	Trooper
Grice, P.	Royal Engineers	Sapper
Grut, C. A.	Divisional Engineers, R.N.D.	Sapper
Heymerdingner, F. G.	London Electrical Engineers, R.E.	Sapper
Hornblower, T. J.	Divisional Engineers, R.N.D.	2nd Corpl.
Hume-Williams, R. E.	Army Service Corps	2nd Lieut.

Graduates—*continued.*

Name.	*Corps, etc.*	*Rank.*
Lacey, F. P. S.	Royal Garrison Artillery	2nd Lieut.
Lintott, A. L.	London Rifle Brigade	Captain
Loughlin, H. J.	6th Northampton Regt.	2nd Lieut.
McPherson, A.	16th Highland Light Infantry	2nd Lieut.
Murphy, G. H.	Divisional Engineers, R.N.D.	Corporal
Newell, C. A.	London Electrical Engineers, R.E.	Sergeant
Ollier, G.	Divisional Engineers, R.N.D.	Sapper
Otter, F. L.	London Rifle Brigade	2nd Lieut.
Pells, E. A.	1st London Divisional R.E.	Lieutenant
Platt, F. C.	Divisional Engineers, R.N.D.	Sapper
Preston, E. B.	Northumbrian Divisional R.E.	Corporal
Scotter, W. A.	Royal Engineers	Sapper
Sheppard, J. H. D.	Army Ordnance Department	Lieutenant
Stout, T. S.	Divisional Engineers, R.N.D.	Sapper
Thomson, D. G.	City of Dundee (Fortress) R.E.	Captain
Treherne, J. W.	Royal Engineers	Sapper
Vandermin, C.	18th Royal Fusiliers	Lance-Corpl.
Wood, A. N. G.	7th West Yorkshire Regt.	Private

Students.

Abbott, J. R.	Tyne Electrical Engineers, R.E.	2nd Lieut.
Addicott, H. O.	West Somerset Yeomanry	Private
Albrecht, E. C.	Inns of Court O.T.C.	Private
Alsford, C. J. R.	Royal Naval Reserve	Sub-Lieut.
Alvey, G. B.	6th West Yorkshire Regt.	Lance-Corpl.
Anderson, S. D.	Lancashire (Fortress) R.E.	Sapper
Angus, T. C.	Honourable Artillery Company	Private
Armstrong, H.	Northern Signal Service, R.E.	Corporal
Aylmer, J.	19th Royal Fusiliers	Lieutenant
Bailey, A. J.	Army Service Corps	Private
Ballard, F. L.	Divisional Engineers, R.N.D.	Sapper
Bannister, A.	Divisional Engineers, R.N.D.	Sapper
Bannister, E. G.	19th Royal Fusiliers	Lieutenant
Barnard, L. E.	6th Bedfordshire Regt.	2nd Lieut.
Barnes, W. C.	Wessex R.F.A.	2nd Lieut.
Barnett, E. J.	London Signal Service, R.E.	2nd Lieut.
Barter, A. E.	R.N.V.R.	Leading Seaman
Beavis, E. A.	London Electrical Engineers, R.E.	Corporal
Bedford, A. L.	London Electrical Engineers, R.E.	Sapper
Bedford, J. T.	9th Middlessx Regt.	Lance-Corpl.
Bell, H. G.	7th Lancashire Fusiliers (Reserve)	2nd Lieut.
Benning, B. S.	Royal Naval Air Service	2nd Lieut.
Bicknell, C. R.	Royal Garrison Artillery	2nd Lieut.
Billington, E. J.	Divisional Engineers, R.N.D.	Sapper
Bold, C. A.	Essex (Fortress) R.E.	Sapper
Bolton, C. R.	Lancashire (Fortress) R.E.	Sapper
Bostock, C. W.	Divisional Engineers, R.N.D.	Sapper
Boxall, C. W.	Divisional Engineers, R.N.D.	Sapper
Bramwell, H. P.	12th Argyll and Sutherland Highlanders	2nd Lieut
Broadwood, L. A. T.	London Signal Service, R.E.	Sapper
Brooke, H.	London Electrical Engineers, R.E.	2nd Corpl.
Bullock, C. L.	Divisional Engineers, R.N.D.	Sapper
Burchett, J. H. P.	Divisional Engineers, R.N.D.	Sapper
Burford, W. B.	Royal Engineers (Special Reserve)	2nd Lieut.
Burleigh, R.	Hampshire (Fortress) R.E.	2nd Lieut.

[illegible]—*continued.*

Name.	Unit.	Rank.
[illegible]	Royal Engineers	Sapper
[illegible]	Artists Rifles	Private
[illegible]	Divisional Engineers, R.N.D.	Sapper
[illegible]	[illegible] Cavalry [illegible]	Trooper
[illegible]	London Electrical Engineers, R.E.	Sapper
[illegible]	Divisional Engineers, R.N.D.	Lance-Corpl.
[illegible]	[illegible] Royal Warwickshire Regt.	Private
[illegible]	Warwickshire Yeomanry	Trooper
[illegible]	Royal Field Artillery	Bombardier
[illegible]	[illegible] Regt.	Private
[illegible]	R.N.V.R.	[illegible]
[illegible] D. H.	Royal Engineers	2nd Lieut.
Clifton, J. P	Royal Garrison Artillery	2nd Lieut.
[illegible], A. G	Royal Engineers	Sapper
[illegible], W. W	[illegible] Royal Fusiliers	[illegible]
[illegible], H. W	[illegible] Gloucestershire Regt.	2nd Lieut.
[illegible], F. W	Royal Engineers	Sergeant
[illegible], P. J.	Royal Engineers	2nd Lieut.
Craig, H. S.	London Electrical Engineers, R.E.	Sapper
[illegible], A. E	Royal Engineers	Lance-Corpl.
[illegible]	London Electrical Engineers, R.E.	Sapper
[illegible], E. H	Northern Signal Service, R.E.	2nd Lieut.
[illegible], H. S.	Army Service Corps	[illegible]
[illegible]	[illegible] Highland Light Infantry	Private
[illegible], H. H	Divisional Engineers, R.N.D.	Sapper
[illegible]	Divisional Engineers, R.N.D.	Sapper
[illegible], H. N	King Edward's Horse	Lance-Corpl.
[illegible], G. G.	Divisional Engineers, R.N.D.	Sapper
[illegible], E. A	Divisional Engineers, R.N.D.	Sapper
Debley, W. J. F.	Gloucestershire Yeomanry	Lance-Corpl.
[illegible], M. R	Army Service Corps	[illegible]
[illegible]	London Signal Service, R.E.	2nd Lieut.
Devonald, N.	[illegible] (Fortress) R.E.	Sapper
[illegible]	[illegible] (Fortress) R.E.	Sapper
Donald, J. A.	Divisional Engineers, R.N.D.	Sapper
[illegible], W. A	[illegible] Royal Scots Fusiliers	Captain
Dunham, D.	4th Royal Berkshire Regt.	Private
Dunn, F. G.	[illegible] Royal Fusiliers	[illegible]
[illegible]	North Midland [illegible] R.E.	2nd Lieut.
Easter, C. E.	London Electrical Engineers R.E.	Sapper
[illegible]	Divisional Engineers, R.N.D.	Sapper
[illegible]	[illegible]	2nd Lieut.
Edmunson, E.	[illegible] Engineers R.E.	Sapper
Ethelston, S.	Royal Field Artillery	2nd Lieut.
[illegible]	[illegible] Regt.	2nd Lieut.
Fendick, A. C.	Royal Garrison Artillery	[illegible]
[illegible]	Royal Garrison Artillery	[illegible]
[illegible]	Royal Engineers	[illegible]
[illegible]	[illegible] (Fortress) R.E.	Sapper
Finnis, A. H.	[illegible] Regt.	Private
Fleming, J.	[illegible] Royal Fusiliers	[illegible]
Floyd, L. G.	London Electrical Engineers, R.E.	[illegible]
Forbes, J.	Royal Engineers	Lance-Corpl.
[illegible]	Divisional Engineers, R.N.D.	Sapper
[illegible]	[illegible] Division R.E.	2nd Lieut.
[illegible]	London Electrical Engineers, R.E.	[illegible]
[illegible]	Royal Flying Corps	2nd Lieut.
[illegible]	[illegible] Regt.	[illegible]
[illegible]	[illegible]	2nd Lieut.
Goble, F.	London Electrical Engineers, R.E.	[illegible]
[illegible], D. C	[illegible] R.E.	2nd Lieut.
[illegible]	Divisional Engineers, R.N.D.	Sapper
[illegible]	London Electrical Engineers, R.E.	Sapper
[illegible]	Royal Field Artillery	2nd Lieut.
Gudgeon, S	[illegible] Regt.	2nd Lieut.
Gwyther, H. J.	[illegible] Regt.	Lieutenant
[illegible] H. C.	[illegible] Signal Service, R.E.	2nd Lieut.
Harris, L. G	[illegible] Regt.	Private
[illegible]	London Electrical Engineers R.E.	Sapper
[illegible]	Royal Engineers	[illegible]
[illegible]	[illegible]	Private
[illegible]	London Electrical Engineers R.E.	Sapper
[illegible]	Royal Engineers	Sergeant
[illegible]	[illegible] Artillery [illegible]	Private
[illegible]	[illegible] Regt.	Lieutenant
Hogarth, J. E.	[illegible]	[illegible]
Housden, H. S.	Divisional Engineers, R.N.D.	Sapper
Howarth, A.	[illegible] Regt.	2nd Lieut.
Huntley, C. G	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	Divisional Engineers, R.N.D.	Sapper
[illegible]	Divisional Engineers, R.N.D.	Sapper
[illegible]	Divisional Engineers, R.N.D.	[illegible]
James, E. G.	Royal Engineers	[illegible]
Jones, V. A.	Royal Engineers	Sapper
Kennedy, W. A.	Divisional Engineers, R.N.D.	Sapper
Kerr, W. W	London Electrical Engineers R.E.	Sapper
Kilby, J. W	London Electrical Engineers R.E.	Sapper
Knight, C. S.	[illegible] Royal Fusiliers	[illegible]
Knight, J. M	[illegible]	[illegible]
[illegible]	London Electrical Engineers R.E.	Sapper
[illegible]	Royal Field Artillery	2nd Lieut.
[illegible]	Royal Engineers	Sapper
[illegible]	Warwickshire Yeomanry	Trooper
Lee, H. J.	London Signal Service, R.E.	Sapper
Leeson, B. E.	[illegible] Regt.	[illegible]
Leeson, B. H.	Divisional Engineers, R.N.D.	[illegible]
[illegible]	Royal Field Artillery	2nd Lieut.
Le May, G. N.	Royal Engineers	Sapper
[illegible]	Royal Engineers	Sapper
[illegible]	[illegible]	[illegible]
Macpherson, A. [illegible]	Royal Engineers	[illegible]
Mann, F. H	Divisional Engineers, R.N.D.	Sapper
Marston, G. S.	Royal Engineers	[illegible]
Martin, G. E	Royal Garrison Artillery	2nd Lieut.
Martin, R. O.	Divisional Engineers, R.N.D.	Sergeant
Metcalf, J. N.	London Electrical Engineers R.E.	Sapper
Mattell, B. E. G.	Divisional Engineers, R.N.D.	[illegible]
Morrell, P.	Divisional Engineers, R.N.D.	Sapper

STUDENTS—*continued.*

Name.	*Corps, etc.*	*Rank.*
Morris, C. I.	1st South Midland Brigade, R.F.A.	Gunner
Mould, James	Royal Garrison Artillery	2nd Lieut.
Mowat, J. W.	17th Highland Light Infantry	Private
Newman, S. E.	Divisional Engineers, R.N.D.	Sapper
Nichols, G. R.	Royal Engineers (T.F.)	Lance-Corpl.
Norburn, W. H. J.	Hampshire (Fortress) R.E.	Lance-Corpl.
North, S. B.	30th Batt. Canadian Force	Private
Nunn, J. A.	Royal Engineers	Corporal
Orme, B. S.	Royal Engineers	Sapper
Ostler, P.	Divisional Engineers, R.N.D.	Sapper
Page, W. A. A.	8th Reserve Cavalry Regt.	Private
Peacock, A. D.	21st Royal Fusiliers	Private
Peattie, J. D.	Divisional Engineers, R.N.D.	Lance-Corpl.
Pernet, F. H.	London Electrical Engineers, R.E.	Sapper
Perrin, J. F.	London Electrical Engineers, R.E.	2nd Corpl.
Peter, L. H.	Cornwall (Fortress) R.E.	2nd Lieut.
Philipp, R. C.	Royal Engineers	Lance-Corpl.
Phillips, H. H.	6th Manchester Regt.	Private
Ponter, H. W. F.	12th County of London Regt.	Private
Powell, C. A. W.	Lancashire (Fortress) R.E.	2nd Corpl.
Poynter, H. G.	Royal Field Artillery	2nd Lieut.
Prince, G. R. D.	Kent (Fortress) R.E.	2nd Lieut.
Pritt, S. E.	Royal Engineers	Sapper
Protheroe, E. L. M.	Divisional Engineers, R.N.D.	Sapper
Protheroe, R. N. L.	Divisional Engineers, R.N.D.	Sapper
Pullen, W. W.	Divisional Engineers, R.N.D.	Sapper
Puttick, H. W.	Divisional Engineers, R.N.D.	Sapper
Rawson, S. M.	Royal Fusiliers	Corporal
Reeves-Smith, D.	Royal Engineers	2nd Lieut.
Ricci, R. E.	H.M. Hospital Ship *Asturias*	Senr. Wireless Officer
Richardson, W.	6th Manchester Regt.	Private
Roberts, A. C.	Divisional Engineers, R.N.D.	Sapper
Robertson, J. N.	Divisional Engineers, R.N.D.	Sergeant
Rodwell, J. T.	Queen's Westminster Rifles	Private
Ross-Bain, G.	7th Manchester Regt.	2nd Lieut.
Ryle, P. J.	20th Royal Fusiliers	Private
Sadler, C. W. C.	4th Seaforth Highlanders	Private
Saxton, C.	Divisional Engineers, R.N.D.	Sapper
Searle, A. M.	London Electrical Engineers, R.E.	Sergeant
Shaw, C. G.	London University O.T.C.	Cadet
Sherwell, O. W.	Royal Field Artillery	2nd Lieut.
Shuter, E. J.	Divisional Engineers, R.N.D.	Sapper
Sinclair, W.	Royal Army Medical Corps	Private

STUDENTS—*continued.*

Name.	*Corps, etc.*	*Rank.*
Sizer, N.	Royal Engineers	2nd Lieut.
Skevington, F. K.	8th Rifle Brigade	Private
Sleight, E. W.	18th Royal Fusiliers	Private
Smith, L. C. R.	6th Royal West Kent Regt.	2nd Lieut.
Smith, L. W.	London Electrical Engineers, R.E.	Sapper
Smith, R. H.	University of London O.T.C.	2nd Lieut.
Smith, S. B.	Royal Navy	Sub-Lieut.
Snowden, S.	9th Middlesex Regt. (Reserve)	Lieutenant
Sparks, A. C.	Royal Engineers	2nd Lieut.
Speed, L. C.	Army Service Corps	Private
Spencer, W. G.	Divisional Engineers, R.N.D.	Sapper
Squire, J. H.	Somerset R.H.A.	Sergeant
Stade, G. H.	Army Service Corps	Private
Stafford, R.	5th Royal Lancaster Regt.	Private
Steele, J.	London Electrical Engineers, R.E.	2nd Corpl.
Stephens, C. A.	Divisional Engineers, R.N.D.	Sergeant
Swinton, E.	Royal Field Artillery	2nd Lieut.
Tabor, A. R.	Royal Field Artillery	2nd Lieut.
Taylor, K. B.	5th Royal Welsh Fusiliers	Captain
Thomas, E.	21st Lancers	Trooper
Thornton, J. M.	Royal Engineers	2nd Lieut.
Troutet, F.	8th Regt. French Army Engineers	
Trouton, D. G.	Royal Field Artillery	2nd Lieut.
Trutch, C. J. H.	London Electrical Engineers, R.E.	2nd Corpl.
Tufnell, C. P.	London Electrical Engineers, R.E.	Sapper
Turton, T. C.	21st Royal Fusiliers	Private
Underwood, C. L.	Divisional Engineers, R.N.D.	Sapper
Websdale, G. J.	Royal Engineers	2nd Lieut.
Webster, H. B.	Royal Garrison Artillery	2nd Lieut.
Wells, R. I.	University of London O.T.C.	Cadet
Weston, J. F.	17th Liverpool Regt.	Private
Wheeler, P. J.	Royal Field Artillery	2nd Lieut.
Wilson, T. P.	Army Service Corps (T.F.)	Driver
Windle, J. B.	Lancashire & Cheshire R.G.A.	2nd Lieut.
Wood, D. S.	Royal Army Medical Corps (T.F.)	Quartermaster
Wood, P. J.	London Irish Rifles	Private
Woodside, H.	Divisional Engineers, R.N.D.	Sapper
Wooler, L. S.	Royal Field Artillery	Bombardier
Woolley, T. G.	East Lancashire Divisional R.E.	Lieutenant
Young, C. N.	University of London O.T.C.	Cadet
Young, W.	Divisional Engineers, R.N.D.	Sapper

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THE SHAPE OF THE PRESSURE WAVE IN ELECTRICAL MACHINERY.

Part I. By S. P. Smith, D.Sc., Associate Member, and R. S. H. Boulding, B.Sc., Student.

Part II. By S. P. Smith, D.Sc., Associate Member.

[illegible]

SUMMARY.

PART I.

[illegible]

[illegible]

[illegible] Introduction.

1. [illegible] windings.
   (a) [illegible] windings.
   (b) [illegible] windings.
   (c) [illegible] distributed windings.

2. General expression for the electromotive force induced in a coil.
   (a) Effect of coil-span—The Coil-span Factor.

3. [illegible]

I. Uniformly-distributed windings.
   (a) Rectangular flux distribution.
   (b) Trapezium flux distribution.
   (c) General flux distribution.

II. [illegible]
   (a) [illegible]
   (b) [illegible]
   (c) Effect of slotting the rotor.

III. Virtual value of the electromotive force induced in a winding.

4. [illegible]
   (a) [illegible]
   (b) [illegible] flux.

[illegible]

PART II.

[illegible] obtained in Part I, by means of the [illegible] the position [illegible] given.

1. [illegible]
   (a) [illegible]
   (b) [illegible]
   (c) [illegible]
2. [illegible]
   (a) [illegible]
   (b) [illegible]

SYMBOLS USED.

[illegible]

L = axial length of core over which B extends.
m = number of coils in a group of a circuit.
N = number of groups of m coils in a circuit.
N_p = number of phases.
n = order of harmonic, or speed in revs. per min.
p = number of pole-pairs.
Q = number of slot-pitches per pole-pitch $= \frac{s}{2p}$.
Q_0 = nearest integer below Q.
Q_1 = number of slot-pitches in coil-span.
q = number of slots per pole and per phase.
R = number of rotor slot-pitches per pole-pitch.
S = arc over which group of m coil-sides extends in uniformly distributed winding.
s = total number of armature slots $= 2pQ$.
T = number of turns in a circuit $= cT_c = mNT_c$.
T_c = number of turns in a coil.
t = time.
u = number of coil-sides per slot.
v = peripheral speed $= 2f\tau$.
x and x' = linear displacements in field of the two sides of a coil.
y_c = commutator pitch, measured in commutator bars.
y_r = resultant winding-pitch, measured in coil-sides $= 2y_c$.
y_b and y_f = back and front winding-pitches, measured in coil-sides.
α—see Fig. 6(a).
β—see Fig. 6(b).
γ = angle in radians between successive armature slots.
ϵ = angular deviation of coil-span from pole-pitch.
θ_x and $\theta_{x'}$ = angular displacements in field of the two sides of a coil, corresponding with x and x'.
τ = pole-pitch.
Φ = flux per pole $= \tau L B_{mean}$.
χ = angular displacement in field between successive groups of coils.
ψ = angular displacement in field between successive coils.
$\omega = 2\pi f$ = angular velocity.

All dimensions are in centimetres.

Part I.

Introduction.

One of the greatest advances that have been made in the development of electromagnetic machinery during the present century is the approach in the shape of the pressure wave to the ideal sine curve.

Several reasons have combined to bring about this result, many of which are indirectly due to the direction in which electrical engineering has developed. Thus the wide extension of the 3-phase system with star-connected generators has removed from the interlinked or line pressure the third harmonic, which is sometimes considerable in the phase pressure. Again, the adoption of the non-salient-pole construction for the rotors of turbo-alternators has made it possible to obtain a flux distribution which remains nearly sinusoidal under all conditions of load, as was shown in a paper read before the Institution by one of the authors.* Finally, the designer has also learnt what refinements are necessary in order that the pressure curve may be free from ripples, although such means are not always used for this purpose alone. For example, the use of a winding with a fractional number of slots per pole will be seen to be one of the best methods of obtaining a smooth pressure curve; yet such windings are usually adopted for altogether different reasons. Also, the improvement consequent on the use of a large number of slots per pole and per phase is primarily due to the increased pole-pitch necessary at high speeds.

Although there are cases where the shape of the pressure wave is not important, there is no doubt that, when once the necessity for a standard is recognized, the pure sine curve is best for general alternating-current working. The arguments in support of this are so well known that they need only be mentioned here. Thus, the troubles occasioned by earthing the neutral, which is now common practice in central-station working, are mainly due to the existence of a third harmonic in the phase pressure. Cases arise also in the parallel working of synchronous machines where the interchange of wattless currents due to the higher harmonics becomes excessive. As an instance, a case may be cited of a 6-phase rotary converter working direct off a 6-wire, 3-phase generator, where, owing to the harmonics, the current taken when the converter was running light was equal to the normal full-load current.

Numerous other factors of varying importance, such as low losses and high power factor in the system, safety in high-tension working, freedom from disturbances to telephones, and from resonance, etc., all demand an absence of harmonics. Also, when a 4-wire, 3-phase system is used for a lighting supply, the use of a pure sine wave results in the ratio, phase pressure to star pressure, being constant.

Lastly, it must not be forgotten that the sine curve is the most natural standard, and that it is generally attainable, which would not be the case with other wave shapes. Also, the majority of our simple calculations and vector diagrams are only possible on the assumption that the quantities in question vary sinusoidally.

1. Classification of Windings.

A winding consists of a number of circuits arranged in series or parallel to suit the pressure and current required. The armature winding is the one which carries the main current and in which the electromotive force or pressure is induced. In nearly all types of modern electromagnetic machines, this winding is accommodated in slots. The coil-sides are arranged in one or two layers, thus forming a single-layer or double-layer winding. (The advantage of classifying windings in this way has been appreciated by C. A. Adams and C. C. Hawkins.) In a symmetrical N_p-phase winding, the successive phases are $2\pi/N_p$ radians apart, *e.g.* the start of phase I in a 3-phase winding is $2\pi/3 = 120°$ (electrical) from the start of phase II; similarly the ends of these two phases are 120° apart. For the purpose of the present paper it is immaterial how the overhang of the winding is arranged. Much of the matter in this section is amplified in Part II.

(*a*) *Single-layer windings.*—It is customary to use these windings for high pressures and where there are several conductors per slot. There is one coil-side per slot, and in each pole-pitch each phase has its own slots, which thus require an arc of π/N_p radians, or $180/N_p$ degrees.

Single-layer windings are essentially open windings; that is, each phase is complete in itself and has its own

* S. P. Smith. The non-salient-pole turbo-alternator and its characteristics. *Journal I.E.E.*, vol. 47, p. 562, 1911.

[illegible]

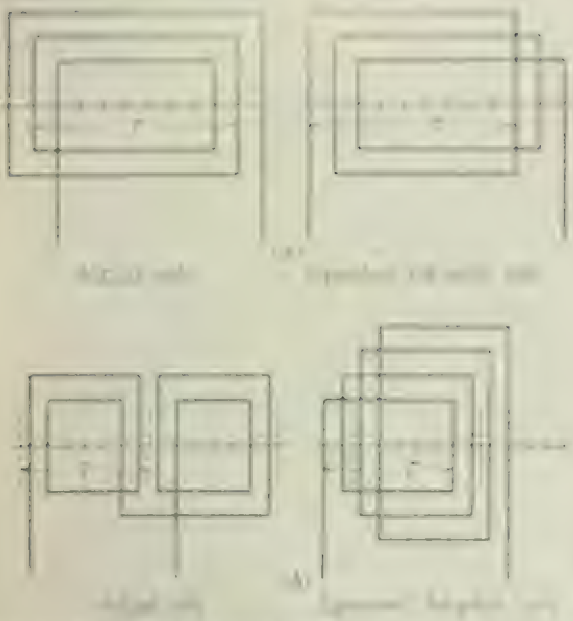


FIG. 1.—[illegible] Windings [illegible]

[illegible] still be replaced by equivalent coils [illegible]

[illegible] are arranged in two layers; one side of each coil lies in the top layer and the other in the bottom layer. The coils can be connected lap or wave. Except with "mixed [illegible] can be greater than, equal to, or less than y.

The double-layer winding is made by using either (1) ordinary open windings with the coils arranged in two [illegible] closed and tapped at certain points, or can be left open, [illegible]

[illegible]

[illegible]

[illegible] of the next).

[illegible] instance, in rotary converters and generators with static balancers. When there are several parallel circuits, as in lap windings, or wave windings with more than two [illegible] can be connected. For this purpose, the number of slots and the number of pole-pairs in the machine are both made divisible by the number of pairs of circuits in the winding, and idle coils are avoided. These conditions place rather serious restrictions on the use of closed [illegible]

[illegible]

parallel, whilst the six terminals can be connected star or delta, as shown (cp. also Figs. 30 and 37).

(c) *Uniformly distributed windings.*—When the number of slots per pole, Q, is an integer, and the field system is not arranged in any abnormal way, the same relative positions in the field will be occupied by the Q slots of every pole-pitch. At any instant, therefore, the coils in the whole winding only occupy Q positions in the field, and the wound parts of each pole-pitch are similarly placed relative to the field system—likewise the unwound parts. Any effect of the slots or teeth will therefore be repeated equally under all poles and will appear at the terminals of the winding. On the other hand, if Q is a fraction, or if the poles or slots are arranged abnormally, this is not so.

Thus if the armature slots or the pole-shoes are skewed by an amount equal to a slot-pitch, the conductors will occupy all possible positions in the field, so that the actual winding becomes equivalent to one distributed uniformly over the whole periphery. Any section of such a winding will then behave as if the armature were not slotted; that is to say, the tooth effects will be nullified at the terminals.

Intermediate cases arise when the pole-shoes are displaced, or the pole-tips are chamfered dissimilarly, or the number of slots per pole is not an integer. For example, if all the North shoes are shifted one-quarter of a slot-pitch in one direction circumferentially, and all the South shoes an equal amount in the other direction, the effect of the teeth is suppressed. Likewise, chamfering the leading pole-tip at one end and the trailing pole-tip at the other end largely reduces the tooth effect. In both these cases the effective distribution of the winding is seen to be increased. Another method whereby the distribution of a winding in which Q is an integer is increased $2p$ times is to place successive pole-shoes a pole-pitch plus $1/2p$th of a slot-pitch apart, so that the distance between the first and the last pole-shoes is a pole-pitch less a slot-pitch. In this way the number of positions occupied by the conductors in the field is $2pQ$, instead of Q.

The commonest of these intermediate cases is when the number of slots per pole is a fraction, and is generally met with in wave windings. To make Q fractional in single-layer windings, extra (empty) slots are inserted. The effect of fractional-pitch coils on the pressure wave is illustrated in Figs. 14 and 22. The magnitude of this effect on the distribution of the winding in the field is examined in Part II, but it is easy to see that with $s = 2pQ_0 \pm 1$, the maximum number of positions in the field obtains. Thus, in the case of a single-layer winding

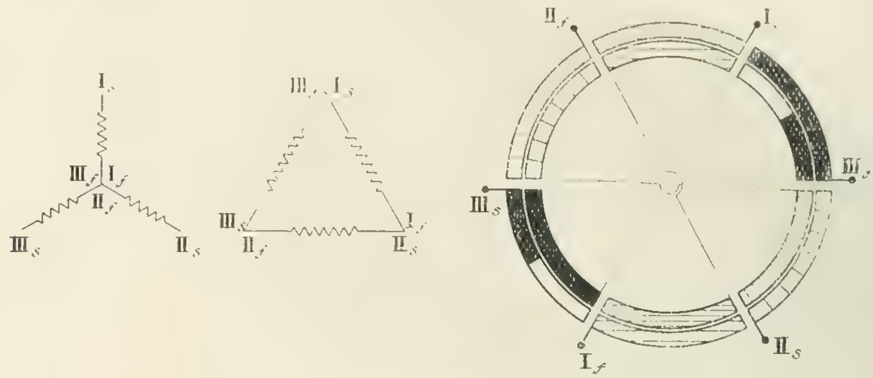


Fig. 3.—Three-phase Double-layer Open Winding.
Each phase covering one-third of each pole-pitch.

with one additional slot, the number of positions occupied by the coil-sides in the field is $2pQ_0$. If there were two extra slots across a diameter, the number of positions would only be increased p times.

The oscillograms shown in Fig. 22 were taken on a 16-pole machine with an open 3-phase coil winding (single-layer) having 3 slots per pole and phase and 6 extra slots (empty) in the periphery.

The oscillograms reproduced in Fig. 14 refer to an open commutator wave winding (double-layer) with 108 slots, 16 poles, and 4 conductors per slot. The winding was star-connected as shown in Fig. 3.

Summing up, then, it is seen that where the number of slots per pole is an integer, and a normal arrangement of slots and poles is adopted, the effect of the teeth will be greatest.

When the poles or slots are skewed in such a manner as to make the conductors occupy all possible positions in the field, the winding is equivalent to a uniformly distributed winding, and the effect of the teeth is nil.

When the pole-shoes are displaced, or the number of slots per pole is fractional, the equivalent distribution of the winding is increased. With respect to the effect of the teeth on the shape of the pressure wave, it will be seen in the course of the paper that these intermediate cases give practically the same result as a uniformly distributed winding.

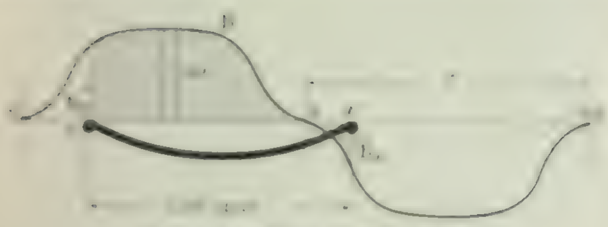
In all cases, therefore, where there is an abnormal arrangement of the field or armature system, or a fractional number of slots per pole, it is allowable in practice to regard the winding as uniformly distributed.

2. General Expression for the Electromotive Force induced in a Coil.

The fundamental expression for the electromotive force induced in a coil is—

$$e = -\frac{d}{dt}\Sigma(T_x \Phi_x)\, 10^{-8} \text{ volts},$$

where $\Sigma(T_x \Phi_x)$ denotes the total magnetic interlinkages.



In a heteropolar machine, the flux interlinking a coil at

harmonics. Since the machine is on open circuit, the flux

Now $\theta_{x'} - \theta_x = \pi \pm \epsilon =$ coil-span,

then $\sin \theta_{x'} = \sin (\pi + \theta_x \pm \epsilon) = -\sin (\theta_x \pm \epsilon)$,

and $\sin \theta_x - \sin \theta_{x'} = 2 \sin \left(\theta_x \pm \frac{\epsilon}{2}\right) \cos \frac{\epsilon}{2} = 2 f_{\epsilon_1} \sin \theta''_x$,

where $$\theta''_x = \theta_x \pm \frac{\epsilon}{2}$$

and $f_{\epsilon_1} = \cos \frac{\epsilon}{2} =$ coil-span factor for fundamental.

Similarly, $f_{\epsilon_n} = \cos n \frac{\epsilon}{2} =$ coil-span factor for nth harmonic.

It will be seen later that the coil-span factor can effectively suppress certain harmonics in the induced pressure. For instance, if the coil spans two-thirds of a pole-pitch, $\epsilon = \pi/3$, then $f_{\epsilon_3} = \cos 3 \left(\frac{\pi}{3 \times 2}\right) = 0$. Or, again, if the number of slots per pole-pair, 2 Q, is odd, and the coil-span is as nearly equal to a full pole-pitch as possible, then $\epsilon = \pm \gamma/2$, and the 2Qth harmonic vanishes from the coil pressure, since $f_{\epsilon_{2Q}} = \cos 2\,Q \left(\frac{\gamma}{2 \times 2}\right) = \cos \frac{\pi}{2} = 0$.

Substituting the coil-span factor in the equation for e—

$$e = 2\, T_c v\, L\, 10^{-8} (B_1 f_{\epsilon_1} \sin \theta''_x + B_3 f_{\epsilon_3} \sin \theta''_x + \ldots)$$

$$= 2\, T_c v\, L\, B_1 f_{\epsilon_1} 10^{-8} (\sin \theta''_x + \frac{B_3}{B_1} \cdot \frac{f_{\epsilon_3}}{f_{\epsilon_1}} \sin 3\, \theta''_x + \ldots)$$

$$= e_{1\max.} \sin \theta''_x + e_{3\max.} \sin 3\, \theta''_x + \ldots e_{n\max.} \sin n\, \theta''_x \quad . \quad (5)$$

where $e_{n\max.} = 2\, T_c\, v\, L\, B_n f_{\epsilon_n} 10^{-8}$.

With full-pitch coils $\epsilon = 0$ and $f_{\epsilon_n} = 1$. The curve of electromotive force, e, induced in a coil is then identical in shape and phase with the B-curve.

3. Electromotive Force Induced in a Circuit of a Winding by Rotation in a Steady Field.*

The next step is to find the electromotive force induced in a number of identical coils displaced from one another in the field and joined in series to form a circuit. These coils may be arranged in one or more equal groups, the successive coils in a group being displaced in the field by the angle ψ, and the successive groups by the angle χ. Thus, in general—

coils in a circuit, $c =$ N groups of coils $\times$ m coils per group.

Let $\Sigma^m_a e$ denote the pressure induced in a group of m coils, then the pressure induced in a circuit is—

$$\Sigma^c_1 e = \Sigma^N_1 (\Sigma^m_a e) \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

If there are T_c turns in a coil, the total number of turns in a circuit is $T = c\, T_c = m\, N\, T_c$.

The number of circuits in which the same pressure $\Sigma^c_1 e$ is induced depends on the position of the slots with respect to the poles. So far as the shape of the pressure wave is concerned, it is immaterial whether identical circuits are joined in series or in parallel, or whether a circuit forms the whole or a part of one or more phases.

When there is a whole number of slots in each pole-pair, the coils in every pole-pair lie in similar positions in the field, and there are as many identical circuits as there are pole-pairs. Each circuit has then only one group of coils, and m can have any value up to the number of coils per pole-pair. Thus when 2 Q is an integer, $N = 1$, $c = m$, and $\Sigma^c_1 e = \Sigma^m_a e$, whilst there are $A = p$ identical circuits.

If 2 Q N is an integer, and the number of slots is not a whole number in fewer than N pole-pairs, there will be a group of m coils in each of the N pole-pairs, and each group will occupy a different position in the field. In this case, a circuit contains $c = N\, m$ coils, and $\Sigma^c_1 e$ is as given in Equation (6).

In order to have A identical circuits in a winding, p/N must be equal to A, also the number of slots must be exactly divisible by A, *i.e.* both p/A and s/A must be whole numbers. These conditions may or may not be satisfied, but should be when the circuits are in parallel. This desirability is well illustrated in the case of double-layer closed windings, where costly experience has often been gained through ignoring these conditions.

In the double-layer arrangement, there are two sets of circuits, and when the A circuits of one set are identical, the A circuits of the other set are also identical. When the double-layer winding is closed, the two sets of circuits are in parallel, thus making $A = a$ pairs of circuits in parallel, or 2 A circuits in all.

A very interesting and important case in practice is the single-layer winding with Q an integer. In this common case, the coil-sides in every pole-pitch occupy similar positions in the field, since for every value of B_x there is a corresponding value $B_{x'} = -B_x$. Hence, if there are m coils in each pole, $\Sigma^m_a e = -\Sigma^m_a e$ in adjacent poles, so that there are two sets of p identical circuits, and the electromotive force induced in the one set of circuits is equal and opposite to that induced in the other set. In this way $2p$ parallel circuits can be obtained in a single-layer winding. An arrangement suitable for this is that marked "actual coils" in Fig. 1(b).

The above arrangements are further dealt with in Part II of the paper.

Before discussing the general case represented by Equation (6), the important practical cases when $\Sigma^c_1 e = \Sigma^m_a e$ will be considered.

For the m coils of a group, let B_a, B_b, . . . B_m and $B_{a'}$, $B_{b'}$, . . . $B_{m'}$ denote the flux-densities in which the respective coil-sides lie, then, as seen from Equation (3), the instantaneous value of the pressure will be—

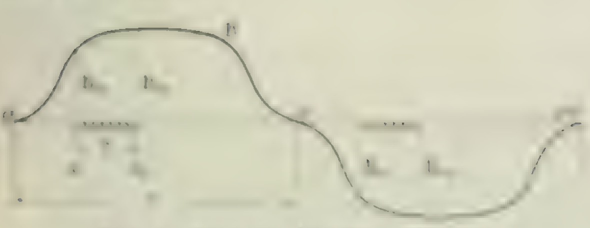
$$\Sigma^m_a e = T_c v\, L\, 10^{-8} \{(B_a + B_b + \ldots) - (B_{a'} + B_{b'} + \ldots)\}$$

$$= T_c v\, L\, 10^{-8} \{\Sigma^m_a B_x - \Sigma^m_a B_{x'}\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

In discussing Equation (7), windings equivalent to uniformly distributed windings will first be considered. The effect of the slots will then be taken into account, after which the general case can be easily followed.

I. *Uniformly distributed windings.*—With the various methods of reducing the tooth effects, it has been mentioned that certain armature windings can be regarded as distributed uniformly over the periphery. Taking the simplest case of a single-layer winding with a whole number of slots per pole and the slots or the pole-shoes skewed by an amount equal to the slot-pitch,

* By a steady field is meant that the flux is constant in value and fixed with respect to the poles.



joined in series to form a phase, etc.

section, or mean angular displacement of the phase in the

$S/\tau = 1/3$. Starting with the centre of the group or phase at o, the electromotive force is zero. As the winding (or field) rotates, the conductors come under the pole one by one and the pressure rises uniformly until the middle of the phase reaches $\pi/3$, when it attains its maximum value. From $\pi/3$ to $2\pi/3$, all the conductors remain under the pole, so that the electromotive force remains steady at its maximum value. After the centre of the phase passes $2\pi/3$, the conductors begin to leave the pole and the pressure falls. This continues until the centre of the group is at π, when the electromotive force is zero. The pressure so that the equation for the pressure $\Sigma_a''' e$ with a rectangular flux distribution over two-thirds of the pole-pitch becomes—

$$\Sigma_a''' e = \frac{24\sqrt{3}}{\pi^2} T f \Phi 10^{-8} \frac{\tau}{S}\left(\sin\frac{S}{\tau}\frac{\pi}{2}\sin\theta - \frac{1}{25}\sin 5\frac{S}{\tau}\frac{\pi}{2}\sin 5\theta - \frac{1}{49}\sin 7\frac{S}{\tau}\frac{\pi}{2}\sin 7\theta\ldots\right) \quad (11)$$

From this general equation the electromotive force curve for any given spread of the armature winding can

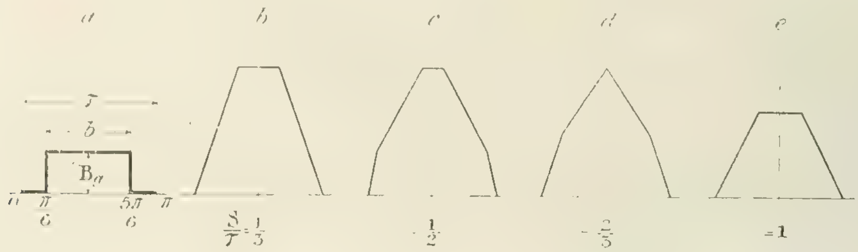


FIG. 7.—Calculated Pressure Curves for Rectangular Flux Distribution with Winding Distributed Uniformly over Arc S of Pole-pitch τ (same number of turns in each case).
Compare with Oscillograms in Fig. 8.

wave thus obtained for a phase of a 3-phase winding is shown in Fig. 7(*b*).

In a precisely similar manner the pressure curve for any other uniform distribution of the winding is obtained. Thus Fig. 7(*c*) for $S/\tau = 1/2$ is the electromotive force curve of a phase of an open 2-phase winding; Fig. 7(*d*) for $S/\tau = 2/3$ is the pressure curve of a 3-phase closed winding with tappings at 120° (3-phase rotary converter) or the terminal pressure of a 3-phase open winding, star-connected. Fig. 7(*e*) for $S/\tau = 1$, represents the pressure of a winding spread uniformly over the whole pole-pitch, as met with in converters with diametral tappings, or with the two phases of a 2-phase open winding joined in series.

These electromotive force waves can also be obtained analytically in the following manner. Taking again the ratio of pole-arc to pole-pitch as 2/3, which is usual for low-speed alternators, the equation for the flux-distribution is found by substituting $\alpha = \pi/6 = 30°$ in Equation (9):—

$$B_x = \frac{4}{\pi} B_g \frac{\sqrt{3}}{2}\left(\sin\theta_x - \frac{1}{5}\sin 5\theta_x - \frac{1}{7}\sin 7\theta_x + \ldots\right).$$

It is seen that with this ratio of pole-arc to pole-pitch, all harmonics whose orders are multiples of 3 vanish in the flux curve, so that there can be no third, ninth, etc., harmonics in the pressure waves. For the remaining flux harmonics—

$$\frac{B_5}{B_1} = -\frac{1}{5};\ \frac{B_7}{B_1} = -\frac{1}{7};\ \frac{B_{11}}{B_1} = \frac{1}{11}\text{ etc.}$$

Also
$$B_g = \frac{\Phi}{\frac{2}{3}\tau L} = \frac{3}{2}\frac{\Phi}{\tau L},$$

and
$$B_1 = \frac{4}{\pi}B_g\frac{\sqrt{3}}{2} = \frac{3\sqrt{3}}{\pi}\frac{\Phi}{\tau L}.$$

Substituting these values in Equation (8), we get for the constant term—

$$2 T v L \frac{2}{\pi}\frac{\tau}{S} B_1 10^{-8} = 2 T (2 f \tau) L \frac{2}{\pi}\cdot\frac{3\sqrt{3}}{\pi}\frac{\Phi}{\tau L} 10^{-8}\frac{\tau}{S}$$
$$= \frac{24\sqrt{3}}{\pi^2} T f \Phi 10^{-8}\frac{\tau}{S},$$

be found. Thus for the cases represented in Fig. 7 we get:—

Phase pressure of 3-phase open winding, $S/\tau = 1/3$ [Fig. 7(*b*)]—

$$\Sigma_a''' e = \frac{36\sqrt{3}}{\pi^2} H\left(\sin\theta - \frac{1}{25}\sin 5\theta + \frac{1}{49}\sin 7\theta\ldots\right)$$

Phase pressure of a 2-phase open winding, $S/\tau = 1/2$ [Fig. (7*c*)]—

$$\Sigma_a''' e = \frac{24\sqrt{2}\sqrt{3}}{\pi^2} H\left(\sin\theta + \frac{1}{25}\sin 5\theta + \frac{1}{49}\sin 7\theta\ldots\right)$$

Phase pressure of a 3-phase converter, or line pressure of star-connected 3-phase winding, $S/\tau = 2/3$ [Fig. 7(*d*)]—

$$\Sigma_a''' e = \frac{54}{\pi^2} H\left(\sin\theta + \frac{1}{25}\sin 5\theta - \frac{1}{49}\sin 7\theta\ldots\right)$$

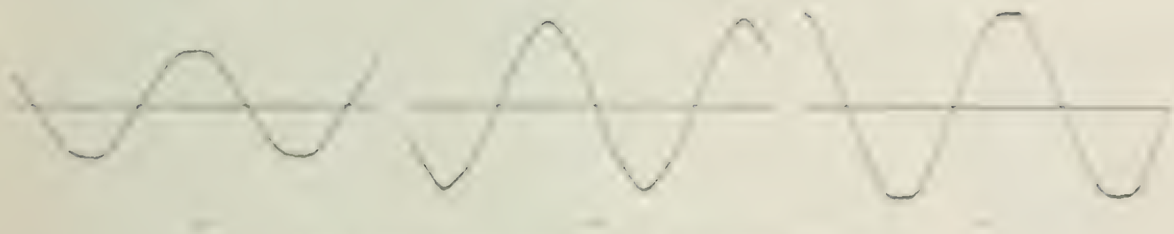
Phase pressure with diametral tappings in a converter, $S/\tau = 1$ [Fig. 7(*e*)]—

$$\Sigma_a''' e = \frac{24\sqrt{3}}{\pi^2} H\left(\sin\theta - \frac{1}{25}\sin 5\theta + \frac{1}{49}\sin 7\theta\ldots\right)$$

where $H = T f \Phi 10^{-8}$.

The graphical method is obviously much simpler, for with other ratios of pole-arc to pole-pitch it is not easy to find the curve represented by the analytical equation without actually plotting it. On the other hand, the graphical method is only simple when the flux curve is a rectangle.

To show that the curves obtained under the assumption of a rectangular flux distribution agree well with those given by actual machines, a comparison may be made with the oscillograms reproduced in Fig. 8. These oscillograms were taken on a rotary converter run as a generator on open-circuit. It is seen that Figs. 8(*a*), 8(*b*), 8(*c*), confirm Figs. 7(*b*), 7(*d*), 7(*e*), respectively.



spread of a uniformly distributed winding can be found at

The harmonics here are all negligible except the third, which is seen to be considerable in the phase pressure, $S/\tau = 1/3$, for a 3-phase winding.

Turning now to the case where the centre part of the pole is left unslotted, a flux distribution is obtained similar to that shown in the oscillogram reproduced in Fig. 9(*a*),

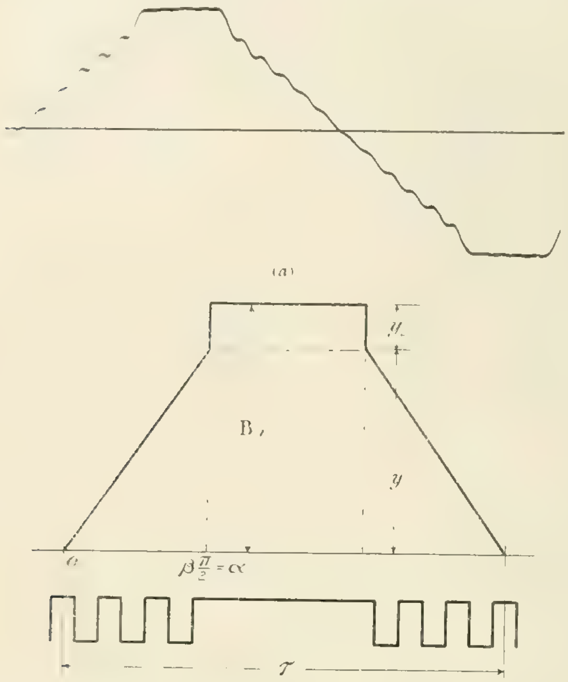


FIG. 9.—Flux Distribution of Non-salient-pole Turbo-alternator with Polar Horn Unslotted.

(*a*) Actual curve. (*b*) Assumed mean curve.

taken on a 2-pole machine with 12 slots per pole, spaced as if there 16, so that $\beta = 3/4$. This curve was taken by placing a conductor in the air-gap, and it is quite permissible to replace it by a trapezium plus a rectangle of base $(1 - \beta)\tau$. An assumed curve of this nature, but for another value of β, is shown in Fig. 9(*b*). Occasionally a steel wedge is placed in the two inside slots of each pole to increase further the width of the rectangular part at the top.

The equation of the curve in Fig. 9(*b*) is—

$$B_x = \frac{8\,y_1}{\pi^2\,\beta}\left(\sin\beta\frac{\pi}{2}\sin\theta_x + \frac{1}{9}\sin 3\,\beta\frac{\pi}{2}\sin 3\,\theta_x + \ldots\right)$$
$$+ \frac{4}{\pi}\,y_2\left(\cos\beta\frac{\pi}{2}\sin\theta_x + \frac{1}{3}\cos 3\,\beta\frac{\pi}{2}\sin 3\,\theta_x + \ldots\right) \quad (13)$$

To find the increase in output obtained by leaving the unwound part of the rotor solid, we must consider the virtual value of the electromotive force. This depends almost entirely upon the fundamental, whence it follows that the output of the machine is increased in the ratio—

$$1 : 1 + \frac{\frac{4}{\pi}\,y_2\cos\beta\frac{\pi}{2}}{\frac{8}{\pi^2\,\beta}\,y_1\sin\beta\frac{\pi}{2}} = 1 : 1 + \frac{\pi\,\beta}{2\tan\beta\frac{\pi}{2}}\cdot\frac{y_2}{y_1}.$$

With $\beta = 2/3$, this ratio becomes $1 : 1 + 0{\cdot}6\; y_2/y_1$
With $\beta = 3/4$, this ratio becomes $1 : 1 + 0{\cdot}5\; y_2/y_1$.

Taking $y_2/y_1 = 1/5$, as in the oscillogram shown, the virtual electromotive force, and therefore the output, are increased 12 per cent when $\beta = 2/3$, and 10 per cent when $\beta = 3/4$.

Regarding the shape of the pressure wave, it is found that the harmonics are not always as small as with the uniformly slotted rotor. For example, with $\beta = 2/3$ and $y_2/y_1 = 1/5$, the pressure induced in a phase of a 3-phase open winding will have a third harmonic of nearly 5 per cent, though all the others will be quite small. Results for any other case can be worked out in a similar way.

(*c*) *General flux distribution—The Distribution Factor.*—Returning to Equation (8), the general expression for the pressure induced in *m* full-pitch coils distributed uniformly over the arc S may be written as follows—

$$\Sigma_a^m e = 2\,T\,v\,L\,10^{-8}\left\{B_1\frac{\sin\frac{S}{\tau}\frac{\pi}{2}}{\frac{S}{\tau}\frac{\pi}{2}}\sin\theta + B_3\frac{\sin 3\frac{S}{\tau}\frac{\pi}{2}}{3\frac{S}{\tau}\frac{\pi}{2}}\sin 3\,\theta + \ldots\right\}$$

$$= 2\,T\,v\,L\,10^{-8}\,(B_1 f_{m_1}\sin\theta + B_3 f_{m_3}\sin 3\,\theta + \ldots) \quad (14)$$

$$= 2\,T\,v\,L\,10^{-8}\,B_1 f_{m_1}\left(\sin\theta + \frac{B_3\,f_{m_3}}{B_1\,f_{m_1}}\sin 3\,\theta + \ldots\right) \quad (14a)$$

where

$$f_{m_1} = \frac{\sin\frac{S}{\tau}\frac{\pi}{2}}{\frac{S}{\tau}\frac{\pi}{2}},$$

$$f_{m_3} = \frac{\sin 3\frac{S}{\tau}\frac{\pi}{2}}{3\frac{S}{\tau}\frac{\pi}{2}},$$

$$\ldots = \ldots\ldots$$

$$f_{m_n} = \frac{\sin n\frac{S}{\tau}\frac{\pi}{2}}{n\frac{S}{\tau}\frac{\pi}{2}}.$$

f_{m_1}, f_{m_3}, . . . f_{m_n} are defined as the distribution factors for the several harmonics, and show the amount by which the harmonics of the B-curve are reduced in the pressure curve by the spread of the winding.

In Table 1 the values of these factors are given for the cases generally met with in practice, whilst in Table 2 the ratios f_n/f_1, defined as the reduction factors, are given as percentages.

By means of these distribution factors we can calculate the pressure $\Sigma_a^m e$ induced in a winding with full-pitch coils, distributed uniformly over any fraction of the pole-pitch, by any flux of which the wave shape is known. Though such a procedure is seldom necessary in practice, these tables are of great interest, for they show the amount by which the flux harmonics are reduced in the pressure curve by the spread of the winding. For example, in a section or winding spread over the whole periphery, $S/\tau = 1$, the magnitude of the distribution factor in per cent is $100/n$; *i.e.* in this case the distribution factors bear the same ratio to one another numerically as the harmonics of a rectangle.

[illegible]

[illegible]

[illegible]					
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	0·056	[illegible]	[illegible]	0·037
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0·030
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	0·033	[illegible]

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	33·3	[illegible]	[illegible]
[illegible]	74·6	[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	−9·1	[illegible]
[illegible]	[illegible]	[illegible]	−7·7	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	−5·9	[illegible]
[illegible]	[illegible]	−5·3	[illegible]	5·3	[illegible]
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of the pressure wave, and then to see to what extent this effect is rendered negligible by making Q fractional, or by shifting the pole-shoes, etc.

Consider a single-layer winding. If s denotes the total number of slots in the periphery, then the slot-pitch in radians will be $\gamma = 2p\,\pi/s = \pi/Q$. The slot-pitch then denotes the angle between successive coil-sides, and the sum of the electromotive forces induced in m coil-sides displaced from one another by the angle γ (see Fig. 10), will be [see Equation (7)]—

$$T_c v L 10^{-8} \Sigma_a^m B_x,$$

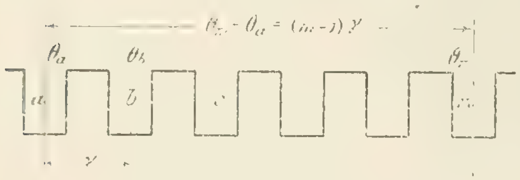


FIG. 10.—Spacing of Slots.

Expanding $\Sigma_a^m B_x$ (see Equation (4) and Fig. 10),

$$\begin{aligned}\Sigma_a^m B_x &= B_a + B_b + \ldots B_m \\ &= B_1(\sin\theta_a + \sin\theta_b + \ldots \sin\theta_m) \\ &\quad + B_3(\sin 3\theta_a + \sin 3\theta_b + \ldots \sin 3\theta_m) + \ldots \\ &= B_1 \frac{\sin\left(\theta_a + \frac{m-1}{2}\gamma\right)\sin\frac{m\gamma}{2}}{\sin\frac{\gamma}{2}} \\ &\quad + B_3 \frac{\sin 3\left(\theta_a + \frac{m-1}{2}\gamma\right)\sin 3\frac{m\gamma}{2}}{\sin 3\frac{\gamma}{2}} + \ldots\end{aligned}$$

Now $\theta_a + \frac{m-1}{2}\gamma = \frac{\theta_a + \theta_m}{2} = \theta =$ displacement of the mid-point of the group of m coil-sides; hence—

$$\Sigma_a^m B_x = m\left\{B_1 \frac{\sin\frac{m\gamma}{2}}{m\sin\frac{\gamma}{2}}\sin\theta + B_3 \frac{\sin 3\frac{m\gamma}{2}}{m\sin 3\frac{\gamma}{2}}\sin 3\theta + \ldots\right\}$$

$$= m(B_1 f_{m_1}\sin\theta + B_3 f_{m_3}\sin 3\theta + \ldots)$$

Similarly, for the other m coil-sides of the group [see Equation (7)]—

$$\Sigma_a^m B_{x'} = m(B_1 f_{m_1}\sin\theta' + B_3 f_{m_3}\sin 3\theta' + \ldots)$$

The distribution factors have now the form—

$$f_{m_1} = \frac{\sin\frac{m\gamma}{2}}{m\sin\frac{\gamma}{2}} = \frac{\sin\frac{m}{Q}\frac{\pi}{2}}{m\sin\frac{1}{Q}\frac{\pi}{2}}$$

$$f_{m_n} = \frac{\sin n\frac{m\gamma}{2}}{m\sin n\frac{\gamma}{2}} = \frac{\sin n\frac{m}{Q}\frac{\pi}{2}}{m\sin n\frac{1}{Q}\frac{\pi}{2}}$$

since $\gamma = \pi/Q$.

In general, if the coil-sides are displaced from one another by the angle ψ, the distribution factor for the nth harmonic is—

$$f_{m_n} = \frac{\sin n\left(\frac{m\psi}{2}\right)}{m\sin n\left(\frac{\psi}{2}\right)}.$$

The influence of the distribution factor on the shape of the pressure wave can now be investigated.

(a) *Whole number of slots per pole—The Spacing Ripple.*—This is the common case with single-layer windings. The actual coils can be replaced by full-pitch coils, so that $\Sigma_a^m B_{x'} = -\Sigma_a^m B_x$; whence the expression for the pressure induced in m full-pitch coils, at angle γ apart, becomes—

$$\Sigma_a^m e = 2\,T\,v\,L\,10^{-8}(B_1 f_{m_1}\sin\theta + B_3 f_{m_3}\sin 3\theta + \ldots) \quad (15)$$

$$= 2\,T\,v\,L\,10^{-8} B_1 f_{m_1}\left(\sin\theta + \frac{B_3}{B_1}\cdot\frac{f_{m_3}}{f_{m_1}}\sin 3\theta + \ldots\right) \quad (15a)$$

where $T = m\,T_c =$ number of turns in a circuit, or, since the same pressure is induced in each of the p identical circuits formed by the groups of m coils of the several pole-pairs, T can refer to a number of circuits in series, *e.g.* a phase. The coil-span factor $\cos n\,\epsilon/2$ is unity for every harmonic.

A closer examination of the distribution factors when Q is integral reveals interesting results. In this common case, where Q is any odd or even number, $2Q$—the number of slots in a double pole-pitch, corresponding with a complete period—will always be even. Further, with steady flux curves, and the positive and negative parts identical, only odd harmonics are present; hence $2Q \pm 1$, $2Q \pm 3, \ldots 2Q \pm x$ and $(M\,2Q \pm x)$ will be possible values of n for the harmonics B_n, where x is any odd number and M any whole number. For these particular harmonics, the distribution factors become—

$$f_{m(2Q-1)} = f_{m(2Q+1)} = \frac{\sin(2Q \pm 1)\frac{m}{Q}\frac{\pi}{2}}{m\sin(2Q \pm 1)\frac{1}{Q}\frac{\pi}{2}}$$

$$= \pm\frac{\sin\frac{m}{Q}\frac{\pi}{2}}{m\sin\frac{1}{Q}\frac{\pi}{2}} = \pm f_1$$

Similarly $\quad f_{m(2Q-3)} = f_{m(2Q+3)} = \pm f_{m_3}$,
and $\quad f_{m(2Q-x)} = f_{m(2Q+x)} = \pm f_{m_x}$,
and $\quad f_{m(M\,2Q-x)} = f_{m(M\,2Q+x)} = \pm f_{m_x}$.

Thus when the number of slots per pole is an integer, the distribution factor does not decrease, as the order of the harmonic n increases, in the same way as with uniformly distributed windings, but periodically rises to a maximum (numerically $= f_{m_1}$) whenever n passes a multiple of $2Q$. For example, with $Q = 6$ or $2Q = 12$, as in a 3-phase winding with two slots per pole and phase ($m = q = 2$), we get $f_{m_n} = f_{m(M\,2Q-1)} = f_{m(M\,2Q+1)} = \pm f_{m_1}$ when $n = 11, 13$; 23, 25; 35, 37; 47, 49, etc. (cp. Table 3). This means that if any of these harmonics are present in the B-curve, they will reappear in the pressure curve $\Sigma_a^m e$ with the same percentage value as the fundamental, whilst the other harmonics are largely reduced by their distribution factors.

[illegible]

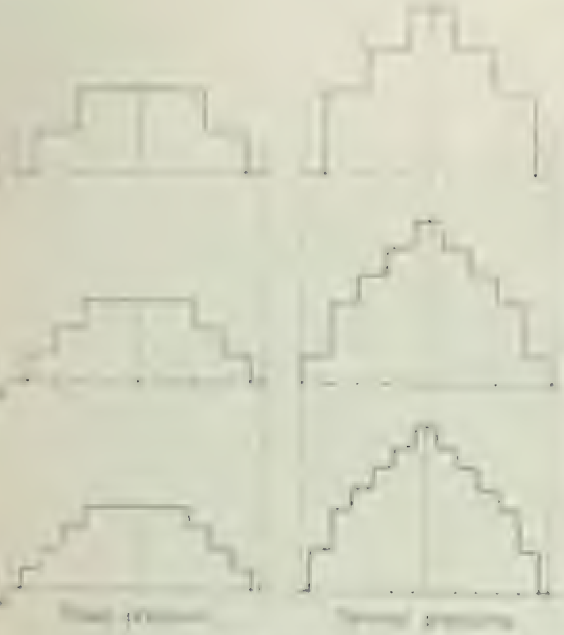
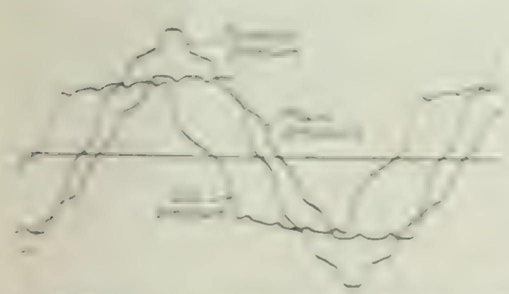


Fig. 11.—The Spacing Ripple.

[illegible]



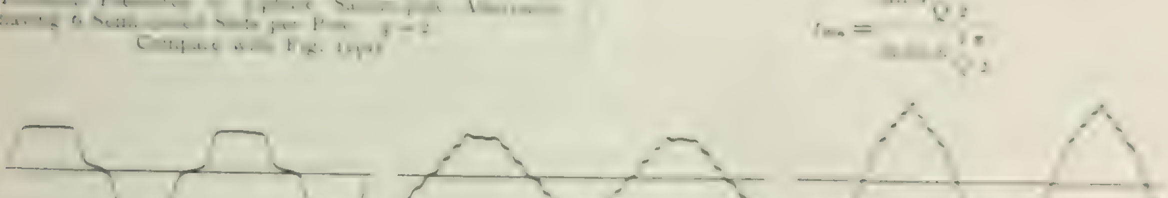
[illegible]

[illegible]

known.

[illegible] the distribution factors. For the sake of comparison, the corresponding values for a uniformly distributed winding [illegible]

$$f_{m} = [illegible]$$



[illegible]

where $m = q$ for the phase pressure, and $m = 2q$ for the interlinked pressure; hence we have

$$f_{mn_{\mathrm{I}}} = \frac{\sin n \frac{q}{Q}\frac{\pi}{2}}{q \sin n \frac{1}{Q}\frac{\pi}{2}} = \frac{\sin n\, 30^\circ}{q \sin n \frac{1}{Q}\frac{\pi}{2}}$$

for phase I, and

$$f_{mn_{\mathrm{I-II}}} = \frac{\sin n \frac{2q}{Q}\frac{\pi}{2}}{2q \sin n \frac{1}{Q}\frac{\pi}{2}} = \frac{\sin n\, 60^\circ}{2q \sin n \frac{1}{Q}\frac{\pi}{2}}$$

for phases I and II in series, so that

$$f_{mn_{\mathrm{I-II}}} = f_{mn_{\mathrm{I}}} \frac{\sin n\, 60^\circ}{2 \sin n\, 30^\circ} = f_{mn_{\mathrm{I}}} \frac{2 \sin n\, 30^\circ \cos n\, 30^\circ}{2 \sin n\, 30^\circ}$$

$$= f_{mn_{\mathrm{I}}} \cos n\, 30^\circ$$

THREE-PHASE WINDINGS WITH WHOLE NUMBER OF SLOTS PER POLE ($Q = 3q$).

TABLE 3.—*Distribution Factors $f_{mn} = f_n$ for Phase Electromotive Force.*

	$q = 2$	3	4	5	6	7	8	9	10	$\frac{S}{\tau} = \frac{1}{3}$
f_1	0·966	0·960	0·958	0·957	0·957	0·957	0·956	0·955	0·955	0·955
f_3	0·707	0·667	0·654	0·646	0·644	0·642	0·641	0·640	0·639	0·636
f_5	0·259	0·217	0·205	0·200	0·197	0·195	0·194	0·194	0·193	0·191
f_7	−0·259	−0·177	−0·158	−0·149	−0·145	−0·143	−0·141	−0·140	−0·140	−0·136
f_9	−0·707	−0·333	−0·270	−0·247	−0·236	−0·229	−0·225	−0·222	−0·220	−0·212
f_{11}	**−0·966**	−0·177	−0·126	−0·110	−0·102	−0·097	−0·095	−0·093	−0·092	−0·087
f_{13}	**−0·966**	0·217	0·126	0·102	0·092	0·086	0·083	0·081	0·079	0·073
f_{15}	−0·707	0·667	0·270	0·200	0·172	0·158	0·150	0·145	0·141	0·127
f_{17}	−0·259	**0·960**	0·158	0·102	0·084	0·075	0·070	0·066	0·064	0·056
f_{19}	0·259	**0·960**	−0·205	−0·110	−0·084	−0·072	−0·066	−0·062	−0·060	−0·050
f_{21}	0·707	0·667	−0·654	−0·247	−0·172	−0·143	−0·127	−0·118	−0·112	−0·091
f_{23}	**0·966**	0·217	**−0·958**	−0·149	−0·092	−0·072	−0·063	−0·057	−0·054	−0·041
f_{25}	**0·966**	−0·177	**−0·958**	0·200	0·102	0·075	0·063	0·056	0·052	0·038
f_{27}	0·707	−0·333	−0·654	0·646	0·236	0·158	0·127	0·111	0·101	0·071
f_{29}	0·259	−0·177	−0·205	**0·957**	0·145	0·086	0·066	0·056	0·050	0·033
f_{31}	−0·259	0·217	0·158	**0·957**	−0·197	−0·097	−0·070	−0·057	−0·050	−0·031
f_{33}	−0·707	0·667	0·270	0·646	−0·644	−0·229	−0·150	−0·118	−0·101	−0·058
f_{35}	**−0·966**	**0·960**	0·126	0·200	**−0·957**	−0·143	−0·083	−0·062	−0·052	−0·027
f_{37}	**−0·966**	**0·960**	−0·126	−0·149	**−0·957**	0·195	0·095	0·066	0·054	0·026
f_{39}	−0·707	0·667	−0·270	−0·247	−0·644	0·642	0·225	0·145	0·112	0·049
f_{41}	−0·259	0·217	−0·158	−0·110	−0·197	**0·957**	0·141	0·081	0·060	0·023
f_{43}	0·259	−0·177	0·205	0·102	0·145	**0·957**	−0·194	−0·093	−0·064	−0·022
f_{45}	0·707	−0·333	0·654	0·200	0·236	0·642	−0·641	−0·222	−0·141	−0·042
f_{47}	**0·966**	−0·177	**0·958**	0·102	0·102	0·195	**−0·956**	−0·140	−0·079	−0·020
f_{49}	**0·966**	0·217	**0·958**	−0·110	−0·092	−0·143	**−0·956**	0·194	0·092	0·019
f_{51}	0·707	0·667	0·654	−0·247	−0·172	−0·229	−0·641	0·640	0·220	0·038
f_{53}	0·259	**0·960**	0·205	−0·149	−0·084	−0·097	−0·194	**0·955**	0·140	0·018
f_{55}	−0·259	**0·960**	−0·158	0·200	0·084	0·086	0·141	**0·955**	−0·193	−0·017
f_{57}	−0·707	0·667	−0·270	0·646	0·172	0·158	0·225	0·640	−0·639	−0·033
f_{59}	**−0·966**	0·217	−0·126	**0·957**	0·092	0·075	0·095	0·194	**−0·955**	−0·016
f_{61}	**−0·966**	−0·177	0·126	**0·957**	−0·102	−0·072	−0·083	−0·140	**−0·955**	0·016
f_{63}	−0·707	−0·333	0·270	0·646	−0·236	−0·143	−0·150	−0·222	−0·639	0·030
f_{65}	−0·259	−0·177	0·158	0·200	−0·145	−0·072	−0·070	−0·093	−0·193	0·015

The chief harmonics in the spacing ripple, *i.e.* $2Q \pm 1$, are in heavy-faced type. A similar table can be worked out for 2-phase windings.

TABLE 4.—*Reduction Factors $= 100 f_n/f_1$ for Phase Electromotive Force.*

	$q = 2$	3	4	5	6	7	8	9	10	$\frac{S}{\tau} = \frac{1}{3}$
f_1	100	100	100	100	100	100	100	100	100	100
f_3	73·2	69·5	68·2	67·6	67·3	67·2	67·1	67·0	66·9	67·7
f_5	26·8	22·7	21·4	20·9	20·6	20·4	20·3	20·3	20·2	20·0
f_7	−26·8	−18·5	−16·5	−15·6	−15·2	−14·9	−14·8	−14·7	−14·6	−14·3
f_9	−73·2	−34·7	−28·3	−25·8	−24·6	−24·0	−23·5	−23·2	−23·0	−22·2
f_{11}	**−100**	−18·5	−13·2	−11·4	−10·6	−10·2	−9·9	−9·7	−9·6	−9·1
f_{13}	**−100**	22·7	13·2	10·7	9·6	9·0	8·7	8·5	8·3	7·7
f_{15}	−73·2	69·5	28·3	20·9	18·1	16·6	15·7	15·2	14·8	13·3
f_{17}	−26·8	**100**	16·5	10·7	8·7	7·8	7·3	6·9	6·7	5·9
f_{19}	26·8	**100**	−21·4	−11·4	−8·7	−7·5	−6·9	−6·5	−6·2	−5·3
f_{21}	73·2	69·5	−68·2	−25·8	−18·1	−14·9	−13·3	−12·4	−11·7	−9·5
f_{23}	**100**	22·7	**−100**	−15·6	−9·6	−7·5	−6·6	−6·0	−5·6	−4·3
f_{25}	**100**	−18·5	**−100**	20·9	10·6	7·8	6·6	5·9	5·4	4·0

[illegible]

Inserting these terms in Equation [illegible], we have—

$$\Sigma_1 e = \Sigma_1^b (\Sigma_a^a e)$$

[illegible]

where—

$T = c\,T = N\,m\,T =$ total number of turns in a circuit and—

[illegible] = group factor of the nth harmonic.

It is seen that the expression for the group factor has the same form as that for the distribution factor.

Equation (16) is the general expression for the electromotive force induced in any circuit of a winding.

[illegible]

reduction factor, and is shown in Tables 2 and 4 as a percentage.

[illegible]

pole-pitch plus or minus a fraction of a slot-pitch it is almost invariably found that the harmonics fall off [illegible]

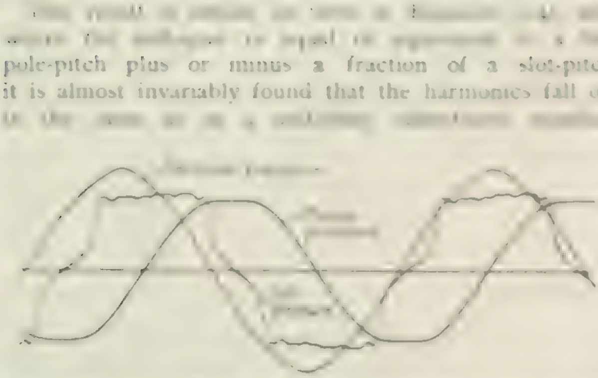


Fig. 14. [illegible]

(cp. Table 9, Part II). This explains why a smooth pressure curve is obtained when Q is fractional.

An illustration of this is given in Fig. 14, showing the pressure induced in a coil, in a phase, and in two phases in series. [illegible]

way, shifting the pole-shoes, etc., increases the effective distribution and thereby makes the winding practically equivalent to a uniformly distributed winding.

(*c*) *Effect of slotting the rotor.* — In modern turbo-alternators it is customary to place the exciting winding in slots cut in the periphery of the rotor, and the authors now propose to investigate the effect of these slots on the shape of the pressure wave. With the rotor slotted, the flux is distributed over the pole-pitch in the form of tufts, the magnitude of which largely depends on the ratio of the slot-opening to the air-gap, and also on the nature of the wedge. In passing it may be mentioned that some or all of the wedges are often made magnetic in order to reduce the gap reluctance.

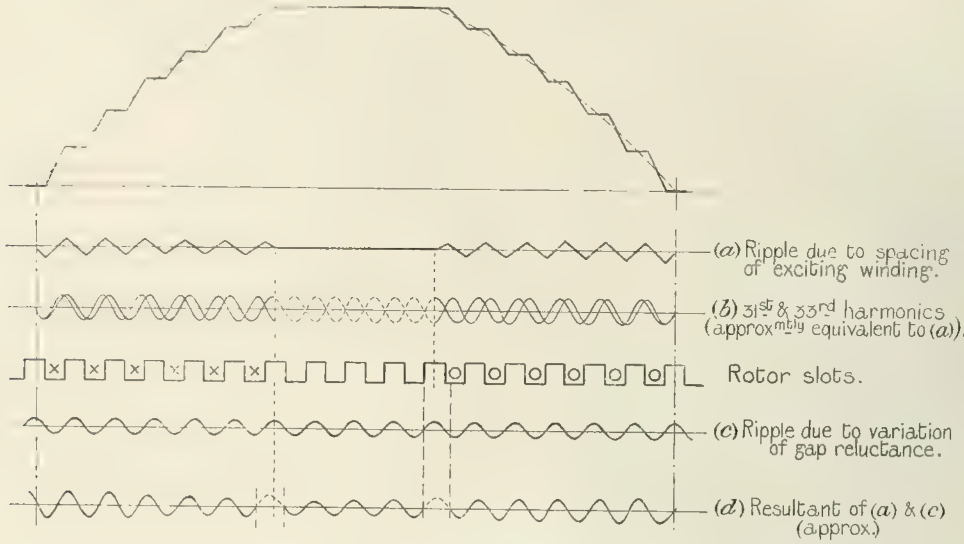


FIG. 15.—Assumed Ripples in Flux Curve due to Slotting of Rotor. 16 Slots per Pole—12 wound. Compare with Coil Pressure in Figs. 16 and 17.

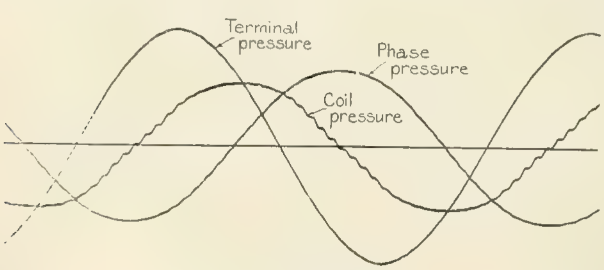


FIG. 16.—Oscillograms showing Effect of Rotor Teeth of Non-salient-pole Turbo-alternator. 24 Stator Slots, nearly closed; 40 Rotor Slots closed with Cast-iron Wedges, 16/20 Wound; 2 Poles. Rotor Slotted uniformly over Whole Periphery.

An examination of the oscillogram reproduced in Fig. 9(*a*), taken on a non-salient-pole turbo-generator, shows that the distribution of the flux does not follow a smooth curve. This is also revealed by the curves marked "coil pressure" in Figs. 16 and 17, which represent the flux distribution—the field being practically steady, owing to the smallness of the stator slot-openings. Any additional effect that might be produced by the flux swinging will be referred to in Section 4.

Fig. 16 was taken from a 2-pole turbo-alternator with 24 stator slots nearly closed and 40 rotor slots closed by cast-iron wedges. The rotor was uniformly slotted over the whole periphery; 16 out of 20 slots per pole wound, and the stator was 3-phase star-connected. Fig. 17 was taken on a 2-pole turbo-alternator also with a uniformly slotted rotor. There were 32 rotor slots, closed by wedges made of laminated iron, and 12 out of 16 per pole were wound. The stator had 60 semi-closed slots with a 3-phase star-connected winding.

It is seen that the ripples in the B-curve (as represented by "coil pressure") have the same spacing as the rotor teeth. The chief ripple is due to the exciting winding being placed in slots [see Fig. 15(*a*)]. This ripple only occurs in the wound part of the pole-pitch, and its amplitude falls off towards the centre, as the flux increases, on account of saturation. A second ripple is due to the variation of gap reluctance caused by the slots and teeth, and exists also in the unwound part, when this is slotted [see Fig. 15(*c*)]. This ripple can be made very small, however, when substantial magnetic wedges are used, as shown in Fig. 16; whilst when the polar horn is left unslotted it disappears from this part altogether, as seen in Fig. 9(*a*).

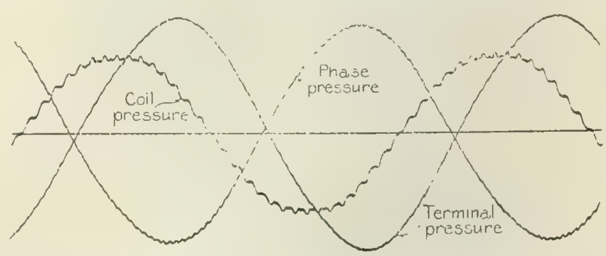


FIG. 17.—Oscillograms of non-salient-pole Turbo-alternator with 60 Stator Slots, Semi-closed; 32 Rotor Slots, 12/16 Wound; 2 Poles. Rotor Slotted uniformly over Whole Periphery. Rotor Wedges—Laminated Iron outside, Brass inside.

Though these two ripples have the same spacing, they

have not the same phase, and in general the ripple in Fig. 15(c) is negligible compared with that in Fig. 15(a), since only open slots without magnetic wedges are used nowadays in the rotor. Considering only the ripple [Fig. 15(d)] due to the concentration of the exciting winding in slots, it can be assumed that its amplitude falls off sinusoidally towards the centre of the pole, and that the ripple itself is a sine curve of frequency 2 R times that of the fundamental. This assumption is justifiable with such small magnitudes, as seen by rounding off the summit of the guided ripple in Fig. 15. Under these assumptions, the ripple in the B-curve will be represented by—

$$B' = B_{max}\cos\theta_r(-\sin 2R\theta_r)$$
$$= -\frac{B_{max}}{2}\left\{\sin(2R+1)\theta_r + \sin(2R-1)\theta_r\right\}$$

This shows that the ripple can be practically replaced by two harmonics of the orders (2 R + 1) and (2 R − 1)—Fig. 15(f). Since R is always a whole number 2 R is always even, and therefore (2 R ± 1) are always odd numbers.*

The effect of the rotor slots, then, is to induce an additional electromotive force, e', in each conductor due to rotation in B', the magnitude of which in a full pitch-coil will be—

$$e' = 2\,l_c\,v\,B'\,10^{-8}$$
$$= -l\,v\,10^{-8}B_{max}\left\{\sin(2R+1)\theta_r + \sin(2R-1)\theta_r\right\}$$

This conclusion is borne out by the oscillograms referred to in the above argument.

Proceeding now to the influence of this flux ripple on the pressure induced in the m coils of a circuit of a winding with Q an integer, it is only necessary to introduce the winding factors for the (2 R ± 1)th harmonics, so that the equation for the additional electromotive force will be—

$$\Sigma_1^m e' = -l\,v\,10^{-8}B_{max}\left\{f_{m(2R+1)}\sin(2R+1)\theta + f_{m(2R-1)}\sin(2R-1)\theta\right\}$$

where $$f_{m(2R-1)} = \frac{\sin(2R-1)\frac{m}{Q}\frac{\pi}{2}}{m\sin\frac{2R-1}{Q}\frac{\pi}{2}}$$

and $$f_{m(2R+1)} = \frac{\sin(2R+1)\frac{m}{Q}\frac{\pi}{2}}{m\sin\frac{2R+1}{Q}\frac{\pi}{2}}.$$

The magnitude of the superposed ripple in the phase or terminal pressure therefore depends on the value of the distribution factors $f_{m(2R\pm1)}$. Now in part (a) of this Section it was found that the distribution factors were generally small, except in the case of the (2 Q ± 1)th harmonics. Unless, therefore, R and Q are nearly equal, the magnitude of $f_{m(2R\pm1)}$ will be fairly small and the superposed ripple $\Sigma_1^m e'$ correspondingly reduced. Thus in Fig. 17, R = 16 and Q = 30, so that for the phase pressure $f_{31} = -0{\cdot}05$ and $f_{33} = -0{\cdot}1$ (see Table 3), and for the terminal pressure $f_{31} = 0{\cdot}043$ and $f_{33} = 0$.

The result of these very low distribution factors is practically to delete the effect of the rotor teeth entirely from the phase and terminal pressures, a fact which is well established by the oscillograms in Figs. 16 and 17. The remaining ripple in these curves has the frequency corresponding to the stator teeth, and is probably due to the flux swinging, as explained in the next section. In Fig. 16, the winding factors $f_{m(2R\pm1)}$ and f_{33} are not quite so small, but the effect of the rotor slots is scarcely visible in the phase and terminal pressures.

If, however, it should happen that 2 R + 1 = 2 Q + 1 or 2 Q − 1, then trouble may be expected. To prove this the curves in Fig. 22 have been reproduced from the oscillograms of a 2-pole turbo-alternator with 32 rotor slots and 48 stator slots. Here 2 R + 1 = 2 Q − 1 = 31, and [illegible] for the phase pressure and [illegible] for the star pressure, so that the effect of the rotor slots on the coil pressure (including the swinging also, see Section d) appears practically undiminished in the phase and terminal electromotive force. It is thus seen that when the numbers of slots per pole-pair on the stator and rotor are equal or only differ by two, a very pronounced ripple of a high order may appear in the pressure; and since the existence of this might lead to very unpleasant consequences, designers should be on their guard against making Q and R nearly or exactly equal to one another.

In conclusion it may be well briefly to recapitulate the results arrived at in this section. The spacing of the armature slots is seen to have a selective influence—with a normal arrangement of slots and poles all the harmonics in the B-curve are reproduced in the pressure induced in each conductor or full-pitch coil, but in the phase and terminal pressures most of these are practically suppressed by their low winding factors, whilst others of the orders 2 Q ± 1 appear very pronounced because their distribution factors approach unity. Hence a harmonic can appear at all in the pressure, it must exist in the B-curve—always assuming the latter to be steady. The winding factor only selects some of these and suppresses the others, and so produces the spacing ripple. Of course a wave with a pronounced ripple may have fewer harmonics than a smooth wave: for instance, if a particular harmonic, say the fifth, were suppressed from the rectangle, the resultant curve would not be nearly so smooth.

The spacing ripple in salient-pole machines is chiefly important with two or three slots per pole and per phase, and unless one of the several methods for making the winding factor very small is used, it is generally advisable, when a smooth pressure wave is needed, to round off the pole tips so as to reduce the harmonics in the B-curve. With non-salient-pole machines the number of stator slots per pole is generally larger, and the chief care must be taken to avoid meeting with the number of teeth on the rotor.

An inspection of the expression for the distribution factor will show that f_{mn} for the nth harmonic can be made zero in the same way as with uniformly distributed windings (see page 211), so that the terminal pressure of a winding filling two-thirds of the slots will have no harmonics, the orders of which are multiples of three.

Hence, with a steady flux, to obtain a pressure of the sinusoidal form from these harmonics there must either be no harmonics in the B-curve, or their winding factors must be so low as to render them negligible. In the case of the tooth effect, the winding factors in question can be

* R represents the number of the rotor slots, no matter whether the [illegible]

made very small by making Q a fraction, or by skewing the slots, or by skewing or displacing the pole-shoes.

III. *Virtual value of E.M.F. induced in a winding.*—The virtual pressure of any wave is—

$$E = \frac{1}{\sqrt{2}} \sqrt{e^2_{1max.} + e^2_{3max.} + e^2_{5max.} + \ldots}$$

where $e_{1max.}$, $e_{3max.}$, etc., are the amplitudes of the several harmonics in the pressure wave.

The virtual value of the pressure induced in a winding can be written—

$$E = k\,T\,f\,\Phi\,10^{-8} \text{ volts,}$$

where k = the E.M.F. coefficient, and depends on the distribution of the flux and of the winding.

It is next proposed to determine k for the various cases which arise in practice. We shall assume uniformly distributed windings with equivalent full-pitch coils, and the slight increase in the value of k for low values of q need not be considered here.

With a *sinusoidal* flux distribution, we have from Equation (14)—

$$\Sigma_a^m e = 2\,T\,v\,L\,10^{-8}\,B_1\,f_{m_1} \sin\theta,$$

where the winding factor f_1 is now equal to the distribution factor f_{m_1}.

$$\text{Therefore } (\Sigma_a^m e)_{max.} = 2\,T\,2\,f\,\tau\,L\,10^{-8}\,\frac{\pi}{2}\,\frac{\Phi}{\tau L}\,f_{m_1}$$

$$= 2\,\pi\,f_{m_1}\,T\,f\,\Phi\,10^{-8},$$

whence

$$E = \frac{1}{\sqrt{2}}\,2\,\pi\,f_{m_1}\,T\,f\,\Phi\,10^{-8}$$

$$= 4{\cdot}44\,f_{m_1}\,T\,f\,\Phi\,10^{-8}.$$

In this case $k = 4{\cdot}44\,f_{m_1}$. This has been worked out for different values of the ratio S/τ, and the results are given in Table 5.

With a *rectangular* flux distribution, as in many salient-pole machines, we have from Equation (9)—

$$B_x = \frac{4}{\pi} B_g \left(\cos\alpha \sin\theta_x + \frac{1}{3}\cos 3\alpha \sin 3\theta_x + \ldots\right)$$

$$= \frac{4}{\pi}\,\frac{\Phi}{b\,L}\left(\cos\alpha \sin\theta_x + \frac{1}{3}\cos 3\alpha \sin 3\theta_x + \ldots\right)$$

Hence by inserting these values in Equation (14), we have—

$$\Sigma_a^m e = \frac{8}{\pi}\,T\,v\,L\,10^{-8}\,\frac{\Phi}{b\,L}\left(f_{m_1}\cos\alpha\sin\theta + \frac{f_{m_3}}{3}\cos 3\alpha \sin 3\theta + \ldots\right)$$

whence the virtual pressure is—

$$E = \frac{1}{\sqrt{2}}\,\frac{8}{\pi}\,T\,v\,L\,10^{-8}\,\frac{\Phi}{b\,L}\sqrt{f_{m_1}^2\cos^2\alpha + \frac{f_{m_3}^2}{9}\cos^2 3\alpha + \ldots}$$

$$= \frac{4\sqrt{2}}{\pi}\,T\,2\,f\,\tau\,L\,10^{-8}\,\frac{\Phi}{b\,L}\,f_{m_1}\cos\alpha,$$

since all the terms under the root, except the first, are negligible. Substituting for b its value [see Fig. 6(*a*)] $\tau\frac{\pi - 2\alpha}{\pi}$, we have—

$$E = \frac{8\sqrt{2}}{\pi}\cdot\frac{\pi\cos\alpha}{\pi - 2\alpha}\,f_{m_1}\,T\,f\,\Phi\,10^{-8}$$

$$= 8\sqrt{2}\,f_{m_1}\,\frac{\cos\alpha}{\pi - 2\alpha}\,T\,f\,\Phi\,10^{-8} \text{ volts,}$$

whence for a rectangular B-curve—

$$k = 8\sqrt{2}\,f_{m_1}\,\frac{\cos\alpha}{\pi - 2\alpha}.$$

In Table 6 the values of k are given for different pole-arcs b.

Similar calculations for non-salient pole machines have also been made. With a *trapezium* B-curve [Fig. 6(*b*)], the E.M.F. coefficient becomes—

$$k = \frac{16\sqrt{2}}{\pi^2}\,f_{m_1}\,\frac{\sin\beta\frac{\pi}{2}}{\beta\left(1 - \frac{\beta}{2}\right)}.$$

This has been calculated for different values of β and is set out in Table 7. With the *polar horn unslotted*—

$$k = 2\sqrt{2}\,f_{m_1}\left\{\frac{\frac{8}{\pi^2}\,\frac{\sin\beta\frac{\pi}{2}}{\beta} + \frac{4}{\pi}\,\frac{y_2}{y_1}\cos\beta\frac{\pi}{2}}{\left(1 - \frac{\beta}{2}\right)\left(1 + \frac{y_2}{y_1}\right) - \frac{y_2}{y_1}\,\frac{\beta}{2}}\right\}.$$

The values of k for $y_2/y_1 = 1/5$, and for different values of β, are given in Table 8. It is quite a simple matter to extend these tables where necessary.

An examination of Tables 5 to 8 shows that, for any given value of S/τ, k is practically constant, except for the rectangle. This is, of course, to be expected when it is recalled that only the rectangle departs appreciably from the sine wave. Except where special investigations are necessary, it is useless to attempt great refinement when designing machines, and no sensible error is introduced by taking a normal mean value for the coefficient k. For practical purposes the values given in Table 6 are sufficiently accurate for normal salient-pole machines. For non-salient-pole machines—with the polar horn either slotted or unslotted—Table 5 can replace Tables 7 and 8 for all practical purposes.

It must be remembered that in the above expression for E, T represents the total number of turns in series in the part of the winding considered, and is only the number of turns per phase when the phase electromotive force is considered. Also Φ is the total flux per pole, irrespective of the distribution. With non-salient-pole machines this is frequently found graphically, especially when the polar horn is unslotted.

When the coils are not equivalent to full-pitch coils, as for example in double-layer chord windings, the coil-span factor must be introduced. The effect, however, is inap-

Table [illegible].

[illegible] Flux Distribution.
([illegible] Machines.)

[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
1	[illegible]

Table [illegible].

[illegible] Flux Distribution [Fig. [illegible]].
([illegible] Machines.)

[illegible]	[illegible]		
	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	4·37
[illegible]	4·37	[illegible]	4·12
[illegible]	4·02	[illegible]	[illegible]
1	[illegible]	[illegible]	[illegible]

Table 7.

[illegible] Flux Distribution [Fig. [illegible]].

[illegible]	Values of [illegible]		
	[illegible]	[illegible]	[illegible]
1/3	4·13	4·22	[illegible]
1/2	3·89	[illegible]	4·03
2/3	3·58	3·65	3·71
1	2·76	2·81	2·86

Table 8.

[illegible] [Fig. [illegible]] and [illegible] = [illegible].

[illegible]	Values of [illegible]		
	[illegible]	[illegible]	[illegible]
1/3	4·23	[illegible]	4·37
1/2	[illegible]	[illegible]	4·12
2/3	[illegible]	3·73	3·79
1	2·82	2·87	[illegible]

[illegible] full pitch.

[illegible]

[illegible] change in amount. It is [illegible]

[illegible]

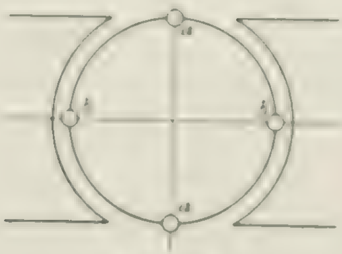


Fig. [illegible]

[illegible] and zero in the position *b–b*. That is, the electromotive force ripple due to the variation of the flux reaches its maximum when the main pressure is zero, and is zero when the main pressure is a maximum.

[illegible] to be damped out by eddy currents and currents induced in the exciting winding. Both experience and experiment [illegible] salient-pole machines ripples are very rarely found in the [illegible] a careful comparison of the measurements published in

two papers by Worrall.* In these experiments flux variations were certainly measured throughout the whole magnetic circuit, but these were very small and quite insignificant compared with those due to swinging. Further, no trace of a ripple is noticeable near the zero of the pressure curves.

In normal machines the effect due to variations in the amount of the flux can therefore be safely disregarded, and this case need not be investigated further here.

(*b*) *E.M.F. ripple due to swinging of total flux.*—This case is of much greater importance, since with laminated shoes there is comparatively little hindrance to the flux swinging. In the worst case the magnitude of this swing would equal the flux of one tooth, and from oscillograms it

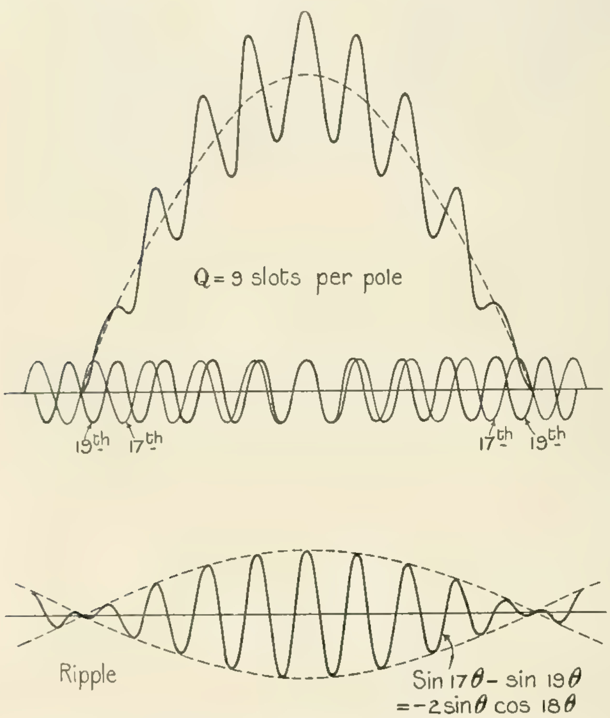


Fig. 19.—Calculated Ripple due to Swinging of Sinusoidal Flux Curve. (E.M.F. induced in a Conductor or Full-pitch Coil.)

is often found to exceed one-half of this amount. The larger the number of teeth per pole the smaller is the possible swing.

The amount of flux-swinging with respect to a coil at any instant depends on the flux-density B_x in which the coil-sides lie; and since the electromotive force due to motion is always proportional to B_x, a pressure will be set up by the flux swinging across the coil in the same way as a pressure is induced by rotation in a steady flux. Thus the pressure induced in a coil can be regarded as due to rotation in a steady field with a superposed ripple due to the field swinging, both of these effects being proportional to the flux-density in which the coil-sides are moving. If, for example, the flux distribution is rectangular—that is, B_x is constant over the polar arc—the amount of flux-swinging across a coil will be the same for all positions of the coil under the pole. In this case, therefore, the pressure wave of a coil will exhibit a constant tooth ripple. On the other hand, if the flux distribution is sinusoidal the maximum ripple electromotive force is induced when the coil-side is under the centre of the pole, the position of maximum flux-density, and this will be the instant when the main pressure is greatest. Thus in this case both the main and the tooth electromotive forces reach their maxima together.

The case of the sinusoidal flux distribution can also be dealt with in a simple analytical manner. Let θ_0 denote the position of the coil relative to the flux (which determines the electromotive force), and $\theta_1 = \omega t$ the position relative to the field system. Then $\theta_1 - \theta_0$ varies periodically with a frequency 2 Q times that of the fundamental. This variation can be expressed by Fourier's series, but since the ripple electromotive force is small compared with the total, it may be assumed to be sinusoidal with the amplitude η, whence—

$$\theta_0 = \theta_1 - \eta \sin 2\,Q\,(\theta_1 + \xi),$$

where ξ fixes the position or phase of the ripple.

Hence for the flux interlinking the coil we get—

$$\Phi = \Phi_{\text{max.}} \cos \theta_0 = \Phi_{\text{max.}} \cos \left\{ \theta_1 - \eta \sin 2\,Q\,(\theta_1 + \xi) \right\}$$

Oscillograms seem to show that this tooth ripple is symmetrical in each half-period of the fundamental.* This was also pointed out by Dr. Howe in recent correspondence in the *Electrician* (June, 1914). By making $\xi = 0$, this condition is fulfilled, as seen in Fig. 19. Moreover, since η is a small angle and $\sin 2\,Q\,\theta_1$ cannot exceed unity, we may write—

$$\sin(\eta \sin 2\,Q\,\theta_1) = \eta \sin 2\,Q\,\theta_1$$

and

$$\cos(\eta \sin 2\,Q\,\theta_1) = 1.$$

By expanding and substituting these values, we get for the flux—

$$\Phi = \Phi_{\text{max.}} (\cos \theta_1 + \eta \sin \theta_1 \sin 2\,Q\,\theta_1),$$

so that the pressure induced in a coil of T_c turns will be—

$$e = -T_c \frac{d\,\Phi}{d\,t} 10^{-8} = T_c\,\Phi_{\text{max.}}\,10^{-8} (\omega \sin \theta_1 - \eta\,\omega \cos \theta_1 \sin 2\,Q\,\theta_1 - \eta\,\omega\,2\,Q \sin \theta_1 \cos 2\,Q\,\theta_1)$$

where $\omega = \dfrac{d\,\theta_1}{d\,t}$.

Since 2 Q is large compared with unity, the second term in the bracket may be neglected, and the electromotive force becomes—

$$e = \omega\,T_c\,\Phi_{\text{max.}}\,10^{-8} (\sin \theta_1 - \eta\,2\,Q \sin \theta_1 \cos 2\,Q\,\theta_1).$$

This shows that the effect of swinging is to produce a ripple of frequency 2 Q times that of the fundamental, whilst its amplitude is proportional to the electromotive force. This is shown in Fig. 19, where the ripple appears largest at the top of the wave and is zero when the electromotive force is zero.

When Q is a whole number, as is usually the case in alternators, 2 Q is always even, consequently the tooth ripple is then even, with the frequency of 2 Q times that of the fundamental. It is possible, however, to replace this even ripple—which must not be regarded as a

* G. W. Worrall. Magnetic oscillations in alternators. *Journal I.E.E.*, vol. 39, p. 206, 1907, and vol. 40, p. 413, 1908.

* Compare Fig. E on page 247.

harmonic, because its amplitude is varying—by two odd harmonics of the orders $2Q \pm 1$. Thus—

$$[illegible]$$

This is a well-known trigonometrical transformation and is illustrated in Fig. 19. Thus the tooth ripple is not an odd harmonic, but may be analysed into two odd harmonics of equal amplitude when Q is an integer. At the point where the pressure wave crosses the datum line these harmonics are zero, whilst at the crest they have the same sign, hence the characteristic appearance of the tooth ripple in the pressure curve.

What has been deduced for a sinusoidal flux distribution holds in a general way for any flux distribution, and the ripple due to the flux-swinging always exhibits similar characteristics.

The amount of flux-swinging depends largely on the constructional details of the machine, such as the number of slots per pole, the ratio of slot-opening to gap, the

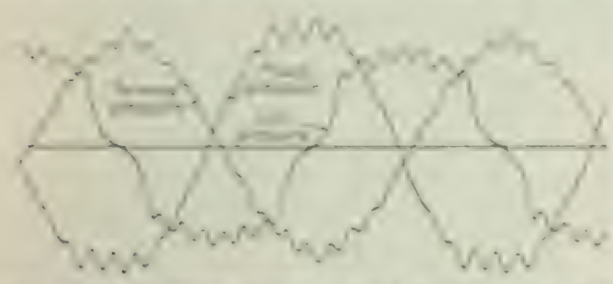


Fig. 20.—[illegible] Q = 3. Open Slots.

skewing of the slots or pole-shoes, etc., and by suitable design it can be made fairly small. The commonest method for reducing the swing is to use nearly closed slots.

The existence of the tooth ripple in the coil electromotive force is no proof that it will exist in the phase or terminal pressure. To find the effect of the tooth ripple on the pressure induced in a circuit it is necessary merely to find the resultant pressure of the [illegible] coils in each of which the electromotive force e is induced. As shown in the previous section, this introduces the winding factor for the several harmonics. Whatever the nature of the flux distribution over the pole-pitch, if the field system is normal and Q is integral the most important harmonics of the tooth ripple will be the same as with a sinusoidal flux wave, namely, the $(2Q-1)$th and $(2Q+1)$th. The winding factors [illegible] of these harmonics become [illegible]

But $$[illegible]$$

That is to say, when Q is an integer, the tooth ripple occurs in the phase pressure with the same percentage value as in the coil pressure. This fact is amply confirmed by experience and is here illustrated in Figs. 20 and 21, which show the tooth ripple of the coil, phase and terminal pressures of 3-phase machines. Fig. 20 is from a salient pole alternator with 9 open slots per pole. Fig. 21 is from a 2-pole non-salient-pole turbo-alternator with [illegible] rotor and 36 stator slots—the slots being semi-closed on each member. The last

[illegible] phase and terminal pressures. The tooth ripple is often [illegible] with a large number of slots, when [illegible] are taken to prevent the flux swinging, as seen in Fig. 17, with [illegible] slots per pole. In this instance it is seen that the distribution factor reduces the small ripple of high frequency and suppresses the larger one of lower frequency. It is thus clear that in a normal machine with a whole number of slots per pole, and in

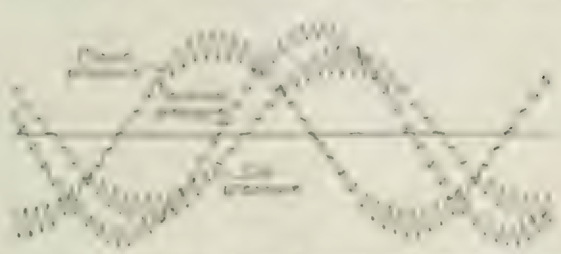


Fig. 22.—[illegible]

which a tooth ripple exists in the coil pressure, there will be a tooth ripple of the same percentage in the phase or interlinked pressure.

When, however, Q is fractional, or the slots or poles are skewed or the poles are arranged in a special way, this is not so. This is due to the fact that the winding factors for the harmonics in the tooth ripple are usually negligibly small with all such arrangements, as has already been explained on page 219.

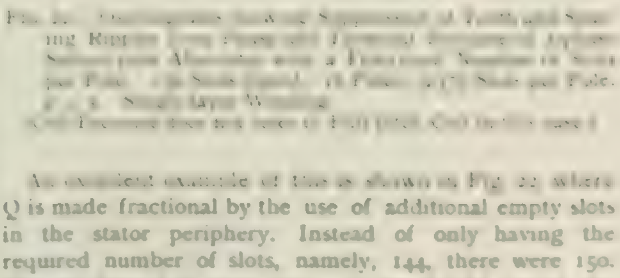


Fig. 21.—[illegible]

An excellent example of this is shown in Fig. 22, where Q is made fractional by the use of additional empty slots in the stator periphery. Instead of only having the required number of slots, namely, 144, there were 150. The machine had open slots. As we should expect, the pressure induced in a conductor reveals a fairly strong tooth ripple, thus proving that the flux was swinging. In the coil pressure the ripple is already reduced owing to the fact that the electromotive forces are not identical in phase; whilst the phase and terminal pressures are quite smooth, thus proving the beneficial action of the

low winding factors for the harmonics contained in the tooth ripple. In this connection, attention may be drawn to the fact that one is accustomed to find that the pressure curves taken at the slip-rings of commutator wave windings are quite smooth—a fact due to the fractional number of slots per pole.

Of course there are external methods of suppressing the tooth ripple from the terminal pressure. For example, a method that has found favour of late years has been the use of a resonance circuit across the terminals of the machine, adjusted to resound with the frequency of the tooth ripple; though in most cases the addition of one or two extra slots would certainly be a much cheaper and an effective way of preventing disturbances in telephones.

Comparing the tooth ripple with the spacing ripple, it has been shown above that they both make their appearance in the pressure $\Sigma_a^m e$, chiefly in the form of two harmonics of the orders $2Q \pm 1$. The spacing ripple, however, occurs with a steady flux, and is due to the selection or retention of these particular harmonics and the practical suppression of the rest, whilst its value is comparatively small when the $(2Q \pm 1)$th flux harmonics are small, as happens when the number of slots per pole and phase is reasonably large, or when the B-curve is nicely rounded off. On the other hand, the tooth ripple is caused by the swinging to and fro of the flux as the teeth enter and leave the field, and is therefore a superposed ripple. It is usually far more in evidence than the spacing ripple.

From what has been said regarding the suppression of the effects due to the slots and teeth, it is obvious that in general it is possible to build machines nowadays in which all such effects are eliminated from the pressure wave.

This paper was written at the City and Guilds (Engineering) College, and the authors desire to thank Professor T. Mather, F.R.S., for the close interest that he has taken in the work. The drawings were made by Mr. J. W. Sims, to whom special thanks are due. Finally, grateful acknowledgments must be made to Messrs. Siemens Brothers Dynamo Works, and to the General Electric Company for permission to reproduce certain oscillograms.

Part II.

WINDINGS AND THEIR VECTOR DIAGRAMS.

Quantities that vary sinusoidally can be represented by vector diagrams. Each harmonic has its own diagram, and the number of vectors will be made equal to the number of coils—not coil-sides—in the circuit. If two or more coils lie in identical positions in the field, their vectors will coincide. The length of each vector in the diagram for the nth harmonic represents—

$$e_{n\max.} = 2\,T_c\,v\,L\,B_n\,10^{-8}\cos n\frac{\epsilon}{2}$$
$$= K\,B_n\,f_{\epsilon n},$$

where $e_{n\max.}$ = amplitude of coil pressure of nth harmonic —see Equation (5), and $K = 2\,T_c\,v\,L\,10^{-8}$ = constant.

To draw the vector diagram for a group of m coils the ordinary clock diagram can be omitted, and the vector polygon at once proceeded with. The resultant is then easily determined. Since the angle between successive vectors is ψ, each vector in the diagram for the fundamental will subtend the angle ψ at the centre. In the diagram for the nth harmonic, each vector subtends the angle $n\psi$; hence the group of m coils will subtend an angle $m\psi$ in the diagram for the fundamental, and $m\,n\,\psi$ in the diagram for the nth harmonic.

If $m\psi = 2\pi,\ 4\pi$, etc., the resultant of the fundamental is zero, and also of every harmonic, since n is an integer. The m coils can then be closed on themselves to form an endless winding. Connections to such windings are made by means of tappings, as in the rotary converter.

The potential difference between any two coils in the winding is the distance between the corresponding points in the vector diagram, and the phase relation of this pressure to the pressure in any other part of the winding is at once obtained from the diagram.

The construction of the vector diagram of the nth harmonic of the electromotive force for a group of m coils

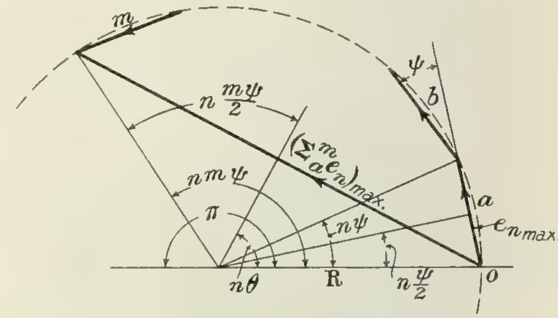


FIG. 23.—Vector Diagram of nth Harmonic (Group of m Coils).

displaced from one another in the field by the angle ψ is shown in Fig. 23. From this diagram it is seen that—

$$\frac{(\Sigma_a^m e_n)_{\max.}}{m\,e_{n\max.}} = \frac{\dfrac{(\Sigma_a^m e_n)_{\max.}}{2\,R}}{m\,\dfrac{e_{n\max.}}{2\,R}} = \frac{\sin n\dfrac{m\psi}{2}}{m\sin n\dfrac{\psi}{2}} = f_{mn}.$$

Thus the ratio of the resultant electromotive force to the sum of the individual electromotive forces is equal to the distribution factor f_{mn}; it is seen how the distribution factor takes the effect of spreading the coils into account.

The instantaneous value $\Sigma_a^m e_n$ is given by the projection of the resultant $(\Sigma_a^m e_n)_{\max.}$ on to the zero line, that is—

$$\Sigma_a^m e_n = f_{mn}\,m\,e_{n\max.}\sin n\,\theta$$
$$= f_{mn}\,f_{\epsilon n}\,m\,K\,B_n\sin n\,\theta.$$

For each of the N different groups of m coils there will be a similar diagram, the successive diagrams being displaced from one another by the angle $n\chi$.

The group factor f_{Nn} is found in the same way as the distribution factor f_{mn}, and is seen to have the same form, namely—

$$\frac{(\Sigma_1^c e_n)_{\max.}}{N(\Sigma_a^m e_n)_{\max.}} = \frac{\sin n\dfrac{N\chi}{2}}{N\sin n\dfrac{\chi}{2}} = f_{Nn}.$$

The resultant electromotive force of the circuit with all the N groups in series will then have the amplitude—

[illegible]

Thus the vector diagram of a circuit of the winding agrees with the general expression deduced analytically in Part I [Equations (16) and (18)].

The general formula and diagram must now be applied to single-layer and double-layer windings.

1. Single-layer Windings

It will be assumed that the actual coils are replaced by coils with the constant span of Q_0 slots or $Q_0\gamma$ radians, where Q_0 is the nearest integer below Q the number of slots per pole, and γ is the slot pitch. These equivalent coils are made by merely re-arranging the overhang without affecting the position of the conductors in the field in any way (see Section 1 of Part I).

When Q is an integer, $Q_0 = Q$ and the equivalent coils span exactly one pole-pitch, i.e. $Q_0\gamma = Q\gamma = \pi$. We then get a winding with full-pitch coils.

If Q is a fraction the equivalent coil span $Q_0\gamma$ [illegible] is less than a pole-pitch by an amount equal to the angle [illegible]. The largest possible number of coils per pole-pair is Q_0.

In the diagram for the fundamental, each vector subtends the angle in the field between successive coils (namely the slot pitch γ radians), so that the vectors of the Q_0 coils of a pole-pair extend over the angle $Q_0\gamma$. Before reaching the coils of the next pole-pair the same angle $Q_0\gamma$ has to be passed. This discontinuity in the diagram is due to the fact that the vectors represent the electromotive forces of coils and not of coil-sides. If only a part of the Q_0 coils in each pole-pair are considered, *e.g.* the coils q of one phase, the angle covered is correspondingly smaller.

The angle between successive vectors in the diagram for the nth harmonic is $n\gamma$. We now proceed to draw the vector diagrams of single-layer windings.

(*a*) *Whole number of slots per pole.*—The author proposes to start with the standard case met with in practice, where the number of slots per pole is an integer, *i.e.* [illegible]. When $Q = Q_0$, the positions of the slots in the field are the same for every pole, and the coils can be replaced by full-pitch coils. The coil-span is then equal to π [illegible]. For the p pole-pairs there are p identical diagrams, each having m vectors, where m is any integer up to Q_0. If $m = Q_0$ the vectors of each diagram for the fundamental subtend the angle $Q_0\gamma = \pi$. If $m = q$ slots per pole and phase, the vector diagram of the coils of a phase in each pole-pair subtends an angle $q\gamma = \frac{Q_0}{N_p}\gamma = \frac{\pi}{N_p}$.

The group factor [illegible] is now equal to unity, since [illegible] as there is no displacement between successive diagrams. Thus when $Q = Q_0 =$ an integer there only remains the distribution factor—

$$f_{dn} = \frac{|\Sigma^m e|}{m\,e} \text{ [illegible]}$$

Example.—[illegible] Fig. [illegible].

[illegible]

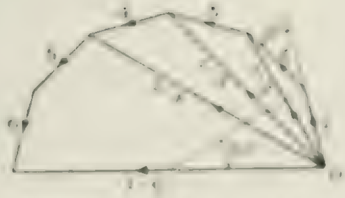


FIG. [illegible]—Vector Diagram of [illegible] Single-layer Winding with Whole Number of Slots per Pole. [illegible]

The effect of [illegible] on the spacing and tooth ripples.

The distribution factors for the 1st, 11th, and 13th harmonics are as follows :—

1 phase of 3-phase winding ($m = 2$) :

$$f_{d1} = \text{[illegible]}$$

1 phase of 2-phase winding ($m = 3$) :

$$f_{d1} = \text{[illegible]}$$

2 phases in [illegible] of a 3-phase winding ($m = 4$) :

$$f_{d1} = \text{[illegible]}$$

1 phase with all coils in series ($m = 6$) :

$$f_{d1} = \text{[illegible]}$$

[illegible]

When used as a 3-phase winding, where the successive [illegible] Fig. [illegible].

[illegible]

A very useful case for turbo-alternators arises from the [illegible] positions in the field. If the vectors were made to repre-

sent the electromotive force of coil-sides instead of coils, then for every vector on one side of the zero line there would be a corresponding vector displaced 180° on the other side. By then choosing m or q divisible by 2 and arranging the overhang of the winding suitably, an equal and opposite electromotive force is induced in each set of $q/2$ coils. The two sets of $q/2$ coils in a pole-pair can

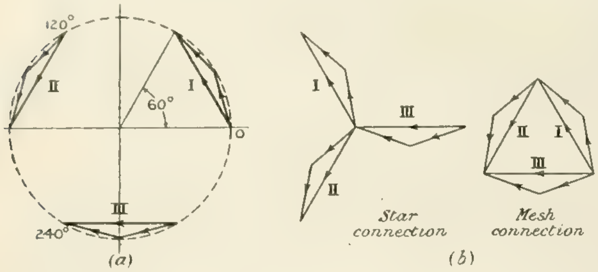


FIG. 25.—Vector Diagram of Fundamental of 3-phase Winding with Whole Number of Slots per Pole. $Q = 6$, $q = 2$.

then be placed in parallel by reversing one set, so that in a machine with $2p$ poles there are $2p$ parallel circuits. In this way, when Q is an integer, it is possible to get as many parallel circuits as there are poles, or $A = 2p$.

For the third harmonic the vectors subtend an angle $3\gamma = 90°$. Each vector is equal to—

$$e_{3\max.} = 2\,T_c\,v\,L\,B_3\,10^{-8}.$$

The vector diagrams for 2, 3, 4, and 6 coils in series are shown in Fig. 26. The same diagram holds for the

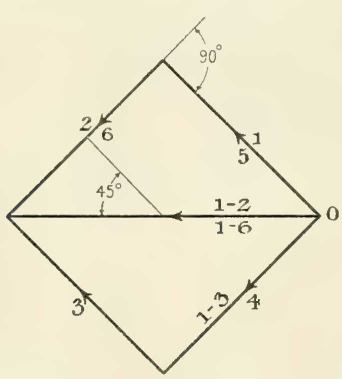


FIG. 26.—Vector Diagram of 3rd and $(2\,Q \pm 3)$th Harmonics of Single-layer Winding with Whole Number of Slots per Pole. $Q = 6$, $n\,\gamma = 90°$.

$(2\,Q \pm 3)$th, *i.e.* the 9th and 15th, harmonics. It is seen that for a two-thirds winding (4 slots wound out of 6) the resultant 1–4 is zero.

With
$$m = 2,\quad f_{m_3} = \frac{(\Sigma_1^2\, e_3)_{\max.}}{2\, e_{3\max.}} = 0{\cdot}707$$

$$= 3,\quad f_{m_3} = \frac{(\Sigma_1^3\, e_3)_{\max.}}{3\, e_{3\max.}} = 0{\cdot}333$$

$$= 4,\quad f_{m_3} = \frac{(\Sigma_1^4\, e_3)_{\max.}}{4\, e_{3\max.}} = 0$$

$$= 6,\quad f_{m_3} = \frac{(\Sigma_1^6\, e_3)_{\max.}}{6\, e_{3\max.}} = 0{\cdot}236.$$

It has been seen that whenever the number of slots per pole is a whole number the pressure wave is characterized by ripples, chiefly made up of the $(2\,Q \pm 1)$th harmonics. It is proposed now to see how a smooth curve of electromotive force can be obtained by making Q fractional.

(*b*) *Fractional number of slots per pole.*—For this purpose one or more (empty) slots are added in the periphery. To investigate the effect of this, it will be assumed that the extra slots are placed round the periphery in such a way that an exact number of identical circuits in a phase is obtained, each having N groups of m coils per group, or $c = N\,m$ coils in each circuit. Identical circuits have identical vector diagrams.

Obviously only circuits with identical electromotive forces are suitable for parallel connection, whilst the series connection has no such limitation. For placing identical circuits in parallel, the start of each circuit must be taken to the one terminal and the finish of each circuit to the other terminal. For the series connection, the finish of one circuit is joined to the start of the next.

In order to obtain A identical circuits let—

$$2\,Q\,N = 2\,Q_0\,N + 1 = \text{an integer},$$

where N is a whole number of pole-pairs: 1, 2, 3, etc. (For example, if $N = 3$ and $Q_0 = 9$, then $2\,Q\,N = 18 \times 3 + 1 = 55 = 54$ wound slots + 1 empty slot.) Since the same slot positions only begin to recur after every N pole-pairs, the latter represent the N different groups of a circuit.

This repetition must recur an exact number of times, in order to obtain A identical circuits in the periphery—it is necessary to have, therefore—

$$s/(2\,N\,Q) = A, \text{ a whole number,}$$

or
$$s = 2\,N\,Q\,A = 2\,N\,Q_0\,A + A.$$

But
$$s = 2\,p\,Q.$$

Hence for A complete repetitions—

$$p = N\,A \text{ or } p/A = N = \text{an integer},$$

and the total number of slots—

$$s = 2\,p\,Q_0 + A.$$

The number of slots in each of the A identical parts is—

$$s/A = 2\,N\,Q = 2\,N\,Q_0 + 1 = \text{an integer}.$$

Thus the conditions for A identical circuits in a single-layer winding are that $\frac{p}{A}$ and $\frac{s}{A}$ are integers, and in the periphery there must be A empty slots equidistant from one another. Thus $A \gtreqless p$. The total possible number of coils in the winding $= p\,Q_0$, and the number of coils in each of the A identical circuits is then $p\,Q_0/A = N\,Q_0$. Thus in the whole periphery there are $N\,Q_0$ different positions and A like positions for the coils. If there are N_p phases, then Q_0/N_p coils belong to each phase in each of the N pole-pairs or groups.

When $A = p$, then $N = 1$. The extra slots can be omitted, and as already discussed in the common case when $Q = Q_0$, it is also possible to make $A = 2p$. When $A = 1$, $N = p$, so that with one extra slot the largest number of positions for the coils is obtained.

For each of the A identical circuits the same vector diagram applies.

To draw the diagram for the fundamental—

$$2QN = sQ_1N \pm 1$$

hence $\qquad Q = Q_1 \pm 1/(2N)$.

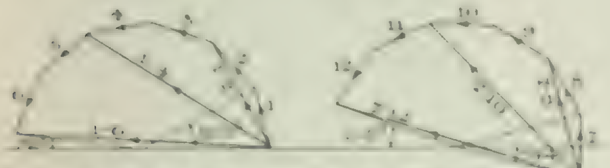
or $\qquad Q_1\gamma = \pi \mp \gamma/(2N)$

and $\qquad Q_1\gamma = \pi \mp \gamma/(2N)$.

Thus the angle covered by the Q_1 coils of each pole-pair $= Q_1\gamma = \pi \mp \gamma/2N$.

An equal angle but occupying a different position is repeated for each of the N pole-pairs or groups of a circuit. Also the angle between the last coil of one pole-pair and the first coil of the next of a circuit is $Q_1\gamma = \pi - \gamma/2N$. The first pole-pair or group starts at 0 and finishes at $Q_1\gamma = \pi - \gamma/2N$. The second group starts at $\pi - \gamma/2N + Q_1\gamma = -\gamma/N$. Hence the angle between the diagrams of successive groups is $-\gamma/N$.

The N vector diagrams for the fundamental can now be at once drawn. For the harmonics, it is readily understood that γ can have any value up to Q.



(a) 1st pole pair. (b) 2nd pole pair.

FIG. 27.—Vector Diagram of Fundamental of Single-layer Winding with Fractional Number of Slots per Pole; $Q = 6\frac{1}{4}$; $\gamma = 28.8°$; 4 Poles; 12 Coils.

As an example consider a winding with only one circuit. In this case all the coils occupy different positions in the field and no parallel circuits are possible. This condition exists when one extra slot is placed in the periphery, *i.e.* A = 1 and $s = 2pQ_1 + 1$, and forms probably the surest way of obtaining a smooth pressure wave with single-layer windings. All the pQ_1 coils now occupy different positions in the field and there are as many different diagrams as there are pole-pairs, *i.e.* N = p.

Example.—Let one extra slot be placed in a 4-pole machine with two slots per pole and phase. Then $Q_1 = 3 \times 2 = 6$ for a 3-phase winding and $s = 4 \times 6 + 1 = 25$.

$$A = 1 \quad N = p/A = 2 \text{ and } \gamma = 180/6\tfrac{1}{4} = 28.8°.$$

The vector diagrams for the fundamental are shown in Figs. 27 (a) and 27 (b)—one for each pole pair, $\gamma Q_1 = 6 \times 28.8°$ and the angle between the two diagrams is—

$$-\gamma/N = -28.8/2 = -14.4°.$$

Each vector has the length—

$$e_{max} = 2\ T_c\ l\ B_z\ 10^{-8} \cos \gamma/2$$
$$= 1.98\ T_c\ l\ B_z\ 10^{-8}.$$

The reduction of the harmonics in this case is seen in the first column of Table 9, and it is noticed that the 11th and 13th (those nearest to 2 Q) have no special interest whatever, clearly showing the effectiveness of this method of suppressing ripples.

The general effect of inserting extra slots in a single-layer winding can best be seen from the winding factors.

With an equal number of identical circuits, *i.e.* when s/A is an integer and $p/A = N$, the following relations hold:—

(1) *Coil-span factor.*—The coil span $Q_1\gamma$ of a single-layer winding with N even is—

$$Q_1\gamma = \pi - \gamma/2N.$$

Then—

$$f_{cn} = \cos n\frac{\gamma}{4N} = \cos n\frac{1}{4N}\cdot\frac{\pi}{Q} = \cos n\frac{1}{2QN}\cdot\frac{\pi}{2}$$

Now 2QN is $sQ_1N \pm 1$, an odd integer and is therefore a possible harmonic in the E curve. When $n = 2QN$

$$f_{c_{2QN}} = \cos \pi/2 = 0,$$

so that no harmonic of the order 2QN can exist in the pressure curve since it will vanish in the E curve.

(2) *Distribution factor.*—The displacement γ in the field between successive coils is the slot-pitch γ, hence—

$$f_{dn} = \frac{\sin n\frac{m\gamma}{2}}{m \sin n\frac{\gamma}{2}} = \frac{\sin n\frac{m\gamma}{2}}{m \sin n\frac{\gamma}{2}} = \frac{\sin n\frac{m}{Q}\frac{\pi}{2}}{m \sin n\frac{1}{Q}\frac{\pi}{2}}$$

(3) *Group factor.*—The displacement γ between successive groups in a single-layer winding is γ/N, hence—

$$f_{Nn} = \frac{\sin n\frac{N\gamma}{2N}}{N \sin n\frac{\gamma}{2N}} = \frac{\sin n\frac{\gamma}{2}}{N \sin n\frac{\gamma}{2N}} = \frac{\sin n\frac{1}{Q}\frac{\pi}{2}}{N \sin n\frac{1}{NQ}\frac{\pi}{2}}$$

(4) *Winding factor.*—From which Q is fractional and there are A identical circuits, the winding factor f_n becomes—

$$f_n = f_{cn}\, f_{dn}\, f_{Nn}$$

$$= \cos n\frac{1}{N\,2Q}\frac{\pi}{2} \times \frac{\sin n\frac{m}{Q}\frac{\pi}{2}}{m \sin n\frac{1}{Q}\frac{\pi}{2}} \times \frac{\sin n\frac{1}{Q}\frac{\pi}{2}}{N \sin n\frac{1}{NQ}\frac{\pi}{2}}$$

$$= \frac{1}{2mN}\,\frac{\sin n\frac{m}{Q}\frac{\pi}{2}}{\sin n\frac{1}{N\,2Q}\frac{\pi}{2}}$$

$$= \frac{\sin n\frac{2m}{s}\frac{A\pi}{2}}{\frac{2m}{A}\sin n\frac{A}{s}\frac{\pi}{2}} = \frac{\sin nK\frac{A}{s}\frac{\pi}{2}}{K \sin n\frac{A}{s}\frac{\pi}{2}}$$

where $K = 2m/A$.

In a 3-phase winding, for the phase pressure

$$m = \tfrac{1}{3} = Q_1/3.$$

Then—

$$K = \frac{2pQ_1}{A\,3} = \frac{2p}{3A}\left(Q - \frac{A}{2p}\right) = \frac{s}{3A} - \frac{1}{3},$$

so that

$$\frac{A}{s} = \frac{1}{3K + 1}$$

Then

$$f_n = \frac{\sin n\frac{K}{3K+1}\frac{\pi}{2}}{K \sin n\frac{1}{3K+1}\frac{\pi}{2}}$$

This simple expression can now be worked out for common values of p and q by evaluating K. The values thus obtained for the reduction factor f_n/f_1 with 1 and 2 extra slots in the periphery are shown as percentages in Table 9, together with the actual values of the winding factor f_1. For the sake of comparison the corresponding values for a uniformly distributed winding with $S/\tau = 1/3$ are given. (When $Q = Q_0$, f_n reduces to f_{mn} by making $A = 2p$ or $N = 1/2$—see Section 5 § *a*.)

The effect of introducing extra slots is remarkably constant, for in every case, both in sign and magnitude, the reduction factor approaches that of a uniformly distributed winding. It is seen that each value of K covers a number of different windings.

Hence the pressure wave will be practically smooth in any machine with one or two extra slots in the periphery.

This is in marked contrast to the standard case where Q is an integer, for here a pronounced ripple, consisting mainly of harmonics of the orders $2Q \pm 1$, is generally observed. When Q is made fractional, by means of extra slots, $2Q \pm 1$ do not represent possible values of n, and the values of f_n for the nearest whole numbers have no special significance.

The question arises whether it is better to use one or two extra slots. Electrically there seems little to choose, but mechanically two slots across a diameter have many constructional advantages. Two extra slots produce no magnetic out-of-balance; they can be conveniently placed at the joints in the case of a split shell; with two extra slots the total number of slots is even, which is often more convenient for the shop tools available; they also admit of two parallel circuits.

On the other hand in a low-speed alternator, one extra slot is quite satisfactory. Regarding a 2-pole turbo-alternator, in the absence of experience, the author is not able to say whether the out-of-balance consequent on the use of one extra slot is permissible.

The great commercial advantages arising from the suppression of ripples in the pressure waves should not be under-estimated. Apart from the importance of preventing disturbances due to ripples, by using extra slots in the

THREE-PHASE SINGLE-LAYER WINDINGS WITH FRACTIONAL NUMBER OF SLOTS PER POLE.

(One or Two Extra (empty) Slots in Periphery.)

TABLE 9.—*Reduction Factors* $= 100\,\dfrac{f_n}{f_1}$ *for Phase Electromotive Force.*

$K = \dfrac{2pq}{A}$	8		12		16		20		24		28		32		36		40		48		Uniformly-distributed winding $\dfrac{S}{\tau} = \dfrac{1}{3}$
	$2p$	q	$2p$	q	$2p$	q	$2p$	q	$2p$	q	$2p$	q	$2p$	q	$2p$	q	$2p$	q	$2p$	q	
A = 1. One extra slot.	2 4	4 2	2 4 6	6 3 2	2 4 8	8 4 2	2 4 10	10 5 2	2 4 6 8 12	12 6 4 3 2	2 4 14	14 7 2	2 4 8 16	16 8 4 2	4 6 12 18	9 6 3 2	4 8 10 20	10 5 4 2	4 6 8 12 16	12 8 6 4 3	
A = 2. Two extra slots across diameter.	4 8	4 2	4 6 8 12	6 4 3 2	4 8 16	8 4 2	4 8 10 20	10 5 4 2	4 6 8 12 16 24	12 8 6 4 3 2	4 8 14 28	14 7 4 2	4 8 16 32	16 8 4 2	4 6 8 12 18 36	18 12 9 6 4 2	4 8 10 16 20 40	20 10 8 5 4 2	4 6 8 12 16 24	24 16 12 8 6 4	

K	8	12	16	20	24	28	32	36	40	48	Uniformly-distributed winding $\dfrac{S}{\tau} = \dfrac{1}{3}$
Winding factor f_1	0·959	0·958	0·958	0·958	0·957	0·956	0·956	0·955	0·955	0·955	0·955
Reduction factor $= 100\,\dfrac{f_n}{f_1}$: f_1	100	100	100	100	100	100	100	100	100	100	100
f_3	69·5	68·5	68·0	67·5	67·5	67·5	67·3	67·2	67·2	67·2	66·7
f_5	24·8	23·1	22·5	21·9	21·6	21·3	21·3	21·3	20·9	20·9	20·0
$-f_7$	11·3	11·3	12·3	13·3	13·3	13·4	13·5	13·6	13·6	13·8	14·3
$-f_9$	23·9	23·2	23·0	22·8	22·6	22·6	22·6	22·6	22·5	22·5	22·2
$-f_{11}$	14·0	12·1	11·4	10·9	10·6	10·3	10·2	10·2	9·9	9·7	9·1
f_{13}	4·5	5·1	6·1	6·3	6·6	6·7	6·8	6·9	7·0	7·1	7·7
f_{15}	15·3	14·3	14·0	13·7	13·6	13·6	13·6	13·5	13·5	13·5	13·3
f_{17}	11·5	9·1	8·2	7·7	7·3	7·1	6·9	6·9	6·7	6·6	5·9
$-f_{19}$	1·8	3·4	3·6	3·9	4·2	4·3	4·5	4·5	4·6	4·7	5·3
$-f_{21}$	12·2	10·7	10·2	10·0	9·9	9·8	9·7	9·7	9·7	9·7	9·5
$-f_{23}$	8·9	7·2	6·9	6·2	5·8	5·6	5·4	5·4	5·2	4·8	4·3
f_{25}	0	1·6	2·2	2·6	2·9	3·0	3·1	3·2	3·3	3·5	4·0

[illegible] ... reduces the cost of [illegible]

[illegible] In this case [illegible]

[illegible]

For the fundamental [Fig. 28(a)]—

[illegible]

For the third harmonic [Fig. 28(b)]—

[illegible]

With [illegible] arrangement any value [illegible] can be given to [illegible] so that a small number of slots per pole and phase can be used. [illegible] the coils of a phase have the same position in each pole-pair, so that the several pole-pairs can be joined in parallel to make $A = p$ parallel circuits if needed.

The uniformly-distributed winding completely removes all effects of spacing of coils and of the teeth.

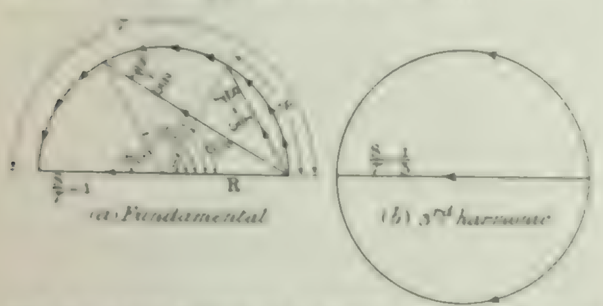


FIG. 28.—Vector Diagram of Uniformly-distributed Winding.

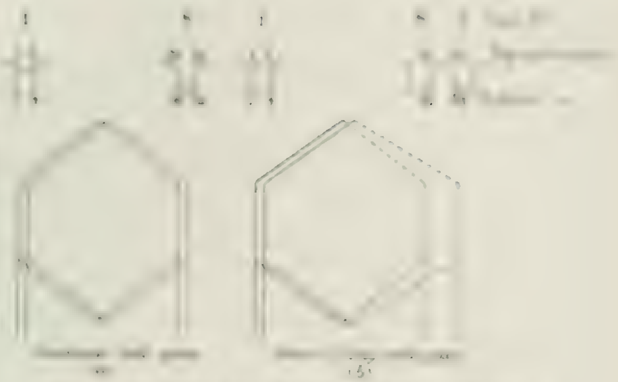
It is seen that the distribution factor has the general form [see Fig. 28(a)]—

$$k_{dn} = \frac{\text{chord}}{\text{arc}} = \frac{2R\sin\frac{\theta}{2}}{\theta R}$$

$$= \frac{\sin\frac{S}{s}\times\frac{\pi}{2}}{\frac{S}{s}\times\frac{\pi}{2}}, \text{ since } \frac{S}{s} = \frac{\theta}{\pi}.$$

[illegible]

[illegible]



[illegible]

When there are only two coil-sides per slot and all the [illegible] equal to the number of slots, s. With u coil-sides per slot [illegible] have any number of turns T_c. In connecting up, the end of coil a is joined to the start of coil b, and the total number of joints or commutator bars is equal to the [illegible] and b are under the same pole-pair, lap connections are [illegible] wave connections (Fig. 33) result.

The chief utility of the double-layer arrangement is to form commutator windings. When connections are made [illegible] the [illegible] periphery and is closed on itself. The double-layer winding is admirably adapted for forming the uniform distribution of the coils over the periphery, while the self-closing is effected by obeying simple winding rules.

[illegible] form of tappings w[illegible] tappings can be conveniently taken off the back of the armature.

[illegible]

of single-layer windings, on account of their mechanical and electrical advantages. For this purpose, open double-layer windings with wave connections are almost invariably employed. From a mechanical point of view it is immaterial whether such open windings are wound according to the closing rules of commutator windings or not; but, electrically, there is a marked difference—see under (*b*). The coil-span $\pi \pm \epsilon = Q_1 \gamma$ can be made greater than, equal to, or less than a pole-pitch, according as the number of slots Q_1 is greater than, equal to, or less than Q. Standard practice is to make the coils span as nearly as possible a full pitch—if ϵ cannot be made zero, it is usually made negative.

(*a*) *Closed double-layer windings* (*commutator windings*).—The chief interest here is the pressure at the slip-rings and not at the commutator. The author proposes first to consider the vector diagram for the fundamental of the induced electromotive force, and then to show how this simple diagram enables the double-layer winding to be clearly understood.

It will be recalled that the vector diagram of a single-layer winding is discontinuous in passing from one group of coils to another. With a closed double-layer winding, however, this is not so, but the vectors run on continuously from coil to coil, until finally the first coil is again reached when the winding closes on itself. The vector diagram then consists of one or more complete polygons, which may or may not be identical. If there are two or more separate, independent windings on the armature, each of which is closed on itself, then each winding has its own vector diagram.

First consider the case where there are two coil-sides per slot; then $C = s$. In this case, ψ, the angle in the field between successive coils in the winding, is constant, and each vector in the diagram for the fundamental sub-

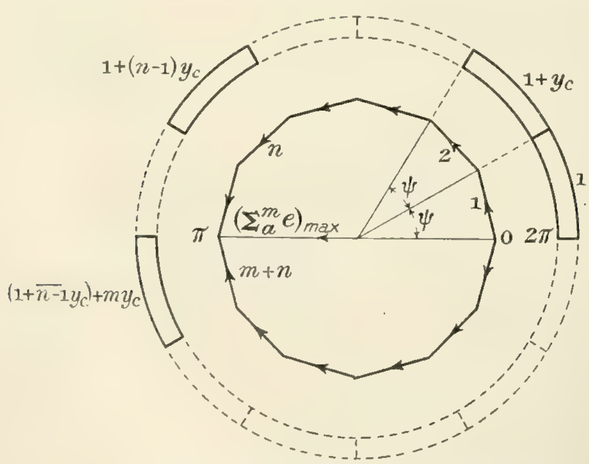


Fig. 30.—Showing Vectors and their Corresponding Commutator Bars.

tends the angle ψ. For the whole winding, the total displacement is $(\Sigma\psi)_{total} = \Sigma_1^s \psi = s\psi$. In order that the winding may close on itself, it is necessary to have in the diagram $s\psi = a\,2\pi$, where $a = 1, 2, 3$, etc., and represents the number of polygons in the vector diagram. If $s/a = 2\pi/\psi$ is a whole number, each polygon has the same number of sides and all the polygons coincide. If s is not exactly divisible by a, this is not so.

In the diagrams for the harmonics, $n\psi$ must be substituted for ψ. These diagrams are also closed, since n is an integer, but they offer no special interest, so that they need not be dealt with further here. On the other hand, the method of constructing the vector diagram for the fundamental allows it to be used for studying the circuits in a closed winding.

(1) *Number of circuits in a closed winding.*—Starting from o in the vector diagram, the electromotive force continues to increase as vectors are added until $\Sigma\psi = \pi$, when it reaches a maximum (see Fig. 30). Beyond π the vectors change in direction, and the pressure falls until it becomes zero when $\Sigma\psi = 2\pi$. If then the coils corresponding with the vectors at o and π are tapped, connection is made with a pair of circuits in the winding. Similarly the vectors between 2π and 4π correspond with a second pair of parallel circuits, and in general the a polygons represent a pairs of circuits. Each tapping to the winding makes connection with one such pair of circuits. It is seen that it is more logical to speak of pairs of circuits than of circuits in a closed winding.

It can now be seen on what the value of a depends.

Since $\qquad s\psi = 2\pi a,$

where $\qquad s = 2pQ$ and $Q\gamma = \pi,$

therefore, by substitution—

$$p\psi = a\gamma, \text{ or } \frac{a}{p} = \frac{\psi}{\gamma}.$$

This simple relation shows clearly how many pairs of circuits there are in a closed commutator winding with two coil-sides per slot.

Thus, if $\qquad a = 1, \quad \psi = \frac{1}{p}\gamma$

$$a = 2, \quad \psi = \frac{2}{p}\gamma$$

$$a = p, \quad \psi = \gamma$$

$$a = a, \quad \psi = \frac{a}{p}\gamma$$

Before applying this relation to lap and wave windings, it is necessary first to see what are the conditions in order that the a pairs of circuits may be identical. A winding in which all the a pairs of circuits are identical is said to be symmetrical.

(2) *Symmetrical closed windings.*—To load a closed winding uniformly, each pair of circuits must be tapped. Hence each slip-ring must go to a points in the winding. Obviously it is only correct to join points in a closed winding which have the same potential at any instant. Thus all the a pairs of circuits must be made identical by arranging them symmetrically on the armature so that they occupy similar positions in the field. Identical pairs of circuits have identical vector polygons. When s is exactly divisible by a, the coils corresponding with identical vectors in the diagram are equidistant, *i.e.* s/a bars apart, on the armature. $s/a = y_p =$ an integer, is called the equi-potential pitch. For these a coils always to have the same potential, however, it is further necessary for them to be in like fields. To satisfy this requirement, the coils must lie an exact number of pole-pairs apart, and, since the a coils are equidistant, this can only occur

[illegible] must be an integer.

Hence in order to have a [illegible] closed winding with two conductors per slot [illegible] must be divisible by a without a remainder.

When there are more than two conductors per slot and there are no idle coils, i.e. [illegible], the symmetry is yet equal provided $\frac{C}{a}$ [illegible] becomes exactly divisible by a. The angle between successive coils in the same slot is no longer constant when [illegible], but the vector diagram can be drawn by using the mean angle [illegible] as when [illegible]. The equipotential pitch measured in bars is [illegible] $= \frac{C}{a}$.

The symmetry conditions limit greatly the number of closed windings suitable for phase tappings, but only such will be considered in this paper. It is true that many continuous-current machines have been built in which [illegible] have not been integers and various artifices have been used to lessen the evil of allowing commutator brushes to make contact with parts of the winding at different potentials. Experience, however, has proved [illegible] the folly of such ventures and the designer is generally well advised to adhere strictly to symmetrical windings. As against an occasional unfavourable pitch the usual practice will secure the best conditions for commutation, heating, efficiency and a good reputation.

(3) *Number of closings in a winding.*—A closed winding may consist of one or more independent windings, each closed on itself. The number of times a winding is closed depends on the relation between the number of commutator bars and the distance between successive coils connected together, *i.e.* between the number of bars C and the commutator pitch y_c measured in commutator bars. In traversing the whole winding of C coils, C y_c bars are passed, since y_c bars are passed in traversing each coil. In traversing C/h coils or 1/hth of the winding C y_c/h bars are passed. Let *h* be the highest common factor of C and y_c; then y_c/h is an integer. Hence in passing C y_c/h bars or tracing out 1/hth of the winding the commutator is traversed an exact number of times; or, in other words, the winding closes whenever C/*h* coils have been traversed. Thus if y_c and C have a highest common factor *h*, the whole winding has *h* closings and there are *h* separate windings on the armature, each containing C/*h* coils.

The *h* windings will have identical circuits only if the conditions of symmetry are satisfied. The latter are independent of the number of closings.

The question arises whether it is an advantage for a symmetrical winding to be singly closed. For the tappings this is immaterial; but for the commutator brushes the singly-closed winding seems to give better results. When there is only one closing, the distribution of the current in the several circuits, by the sliding contact formed by the brushes on the commutator, appears less arbitrary than when there are a number of separate windings. In many designs, therefore, multiply-closed windings are prohibited entirely as well as unsymmetrical windings.

The effect of the number of closings on the vector diagram is illustrated in Example 2 on wave windings.

(4) *Position of the phase tappings.*—Phase tappings are merely equipotential connectors taken at definite places in the winding. [illegible]

[illegible] ing of the [illegible]

[illegible]

In this way [illegible] [illegible] even this can generally be omitted when the above rule is observed.

Since each phase of an N_p-phase system subtends the angle [illegible] of the tappings can be written down at once for these are [illegible] to be tapped are the same as the numbers of the vectors, though the order of the phases may be interchanged, [illegible] phases have more coils than others (unless coils are split) [illegible] by applying the above rule.

(5) [illegible]—The general shape of the pressure wave depends on the amount of the pole-pitch over which the phase extends. Herein lies the chief difference between open and closed windings. In the open winding, each phase is usually [illegible] whilst every tapping serves as the finish of one phase and the start of the next.

[illegible] over 60° in the open winding and 120° in the closed winding. With uniformly distributed windings, the wind- [illegible] with a closed winding as in a 3-phase open winding the former must be made 6-phase.

[illegible]

diametral tappings are generally used, so that $S/r = 1$. The output of the machine is not affected thereby, but of course the shape of the pressure wave is not the same as between tappings at $2\pi/N_p$ radians.

As in single-layer windings, the possibility of ripples in the pressure curve will depend mainly on the number of slots per pole. It will be seen that cases occur where Q can be an integer, whilst in numerous other cases this is not possible.

When Q is an integer, then for the coil-span factor—

$$f_{\epsilon_n} = \cos n\frac{\epsilon}{2} = \cos n\frac{x\gamma}{2}$$

where coil-span $\pi \pm \epsilon = \pi \pm x\gamma$, and $x = 0, 1, 2$, etc., x is made as small as possible to get approximately full-pitch coils. Usually $x = 0$ or ± 1. If $x = 0$, *i.e.* the coils span a full pitch, $f_{\epsilon_n} = 1$ for all harmonics. If $x = 1$, and $n = 2Q \pm 1$, then—

$$f_{\epsilon(2Q\pm 1)} = \cos(2Q \pm 1)\frac{\gamma}{2} = -\cos\frac{\gamma}{2}.$$

This is approximately unity for all practical values of γ. Thus the coil-span factor has practically no influence on the harmonics of the order $2Q \pm 1$, when Q is an integer.

With regard to the distribution factor, $\psi = \gamma$ when there are 2 coil-sides per slot, so that, when $Q = Q_0 =$ an integer, $f_{m(2Q_0\pm 1)} = \pm f_{m1}$, and $f_{m3} = 0$ for $\frac{m}{Q} = \frac{2}{3}$, as in single-layer windings. When there are more than two coil-sides per slot, the effect is practically the same, for the distribution in the field is not altered if the coil-sides of a winding with two coil-sides per slot are subdivided.

Hence when Q is an integer a double-layer winding behaves practically in the same way as a single-layer winding respecting the spacing and tooth ripples.

(6) *Lap windings.*—With lap connections the finish of one coil is joined to the start of another—usually the next—under the same pole-pair. If there are more than two coil-sides per slot, the number of slots can be increased to $C = su/2$ without affecting the position of the commutator bars. The angles ψ_c and γ_c for the increased number of slots are then constant.

In the lap winding, the angle $a = y_c\gamma_c$ between successive coils on the armature is equal to the angle ψ_c between the same coils in the field, hence the commutator pitch—

$$y_c = \frac{a}{\gamma_c} = \frac{\psi_c}{\gamma_c} = \frac{a}{p}$$

$= 1, 2, 3$, etc. [see Fig. 31(*a*) and (*b*)].

Thus $a = y_c p$, or the number of circuits in a lap winding is a multiple of the number of poles, whilst there is no restriction concerning the number of coils, etc.

Measured in coil-sides, $y_s = 2y_c = y_b - y_f$.

The limitations imposed by the conditions of symmetry are very extensive with lap windings. Since $a/p = y_c = 1$, 2, etc., and p/a must be a whole number, it is only possible to have a symmetrical winding when $a = p$ or $y_c = 1$, as in Fig. 31(*a*). The other condition becomes $s/a = s/p = 2Q$ = an integer, that is, the slots per pole must be a whole number or a whole number $+ \frac{1}{2}$.

This is important in regard to the shape of the pressure wave, for when Q is an integer there may be a strong ripple.

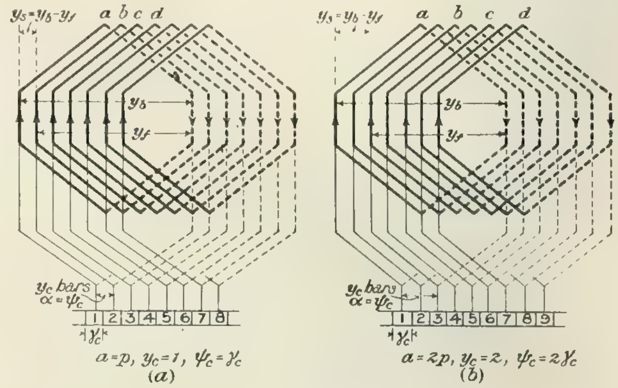


FIG. 31.—Lap Windings.

Example.—As an example, consider lap windings for large 6-phase rotary converters. For pressures of 460 to 600 volts at the commutator and 11 volts between bars as a mean safe working limit, suitable values of bars per pole, to give the same number of coils in each phase, are—

$$\frac{C}{2p} = 42, 48, 54$$

$$y_p = \frac{C}{p} = 84, 96, 108$$

$$\frac{C}{pN_p} = \frac{C}{6p} = 14, 16, 18$$

With eight coil-sides per slot, *i.e.* $u/2 = 4$—

$$2Q = \frac{s}{p} = \frac{2C}{pu} = 21,\ 24,\ 27$$

$$Q = 10\tfrac{1}{2},\ 12,\ 13\tfrac{1}{2}$$

The position of the phase tappings can be at once written down for the above cases. Since $y_c = 1$, the

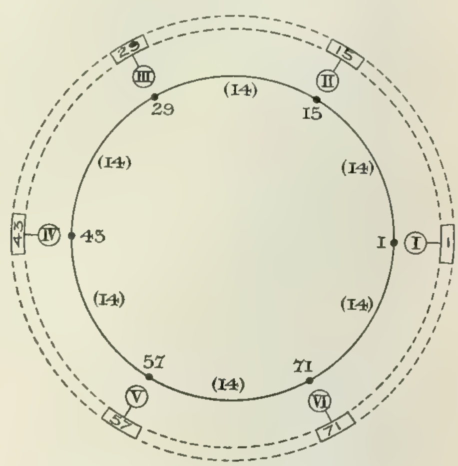


FIG. 32.—Phase Tappings for 6-phase Lap Winding. 84 Commutator Bars per Pole-pair.

All pole-pairs identical—only one pole-pair shown.

vectors have the same numbers as the commutator bars. Taking the first case for instance, where $y_p = 84$ and $\frac{y_p}{6} = 14$, the slip-rings go to bars 1, $1 + 14 = 15$.

[illegible]

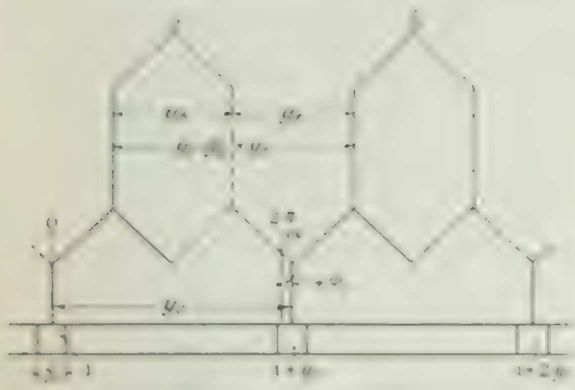


Fig. [illegible].—Wave Winding.
In general, [illegible]

[illegible] of one coil is joined to the start of another coil under the [illegible] is the displacement between the coils in the field (see Fig. [illegible])

Then

[illegible]

or $\pm a = p y_r - C$.

[illegible] restricted by the choice of a and p.

[illegible]

The use of wave windings in practice is also seriously [illegible]

[illegible] but, in the author's opinion [illegible] ence and distrust of wave windings [illegible] pensed with, unless required as phase tappings.

[illegible] commutator wave windings—

[illegible]

[illegible] is a whole number, Q must be a fraction. Thus there is [illegible] alternators where a smooth pressure curve is needed.

Consider now two examples showing how the phase tappings can be located.

[illegible] four poles has 81 commutator bars. Find what bars must be tapped for a (i) 3-phase (ii) 4-phase pressure.

[illegible]

The [illegible] diagram consists of a single polygon with [illegible] diagram is divided into three equal parts. The bars to be tapped correspond with the vectors 1, 1 + 27 = 28, [illegible]

that the order of the phases on the commutator is not the same as that in the diagram, but this is immaterial.

(ii) With 4-phase tappings, $N_p = 4$ and $81/4$ is not an integer. Hence some phases will have more coils than others. Two alternatives will be considered.

Alternative (*a*).—Take $y_c = 41$ and split up the winding into sections of 20, 20, 20, and 21 coils respectively, as shown in Fig. 34(*a*). The bars to be tapped then correspond with the vectors 1, 21, 41, and 61.

Vector 1 = bar 1,
,, 21 = ,, $1 + 41 \times 20 = 1 + 10 = 11$,
,, 41 = ,, $11 + 41 \times 20 = 11 + 10 = 21$,
,, 61 = ,, $21 + 41 \times 20 = 21 + 10 = 31$,
(,, 1 = ,, $31 + 41 \times 21 = 31 + 51 = 1$).

It is always advisable to include the last line, which serves as a check on the accuracy of the working. Thus the bars to be tapped are 1, 11, 21, and 31.

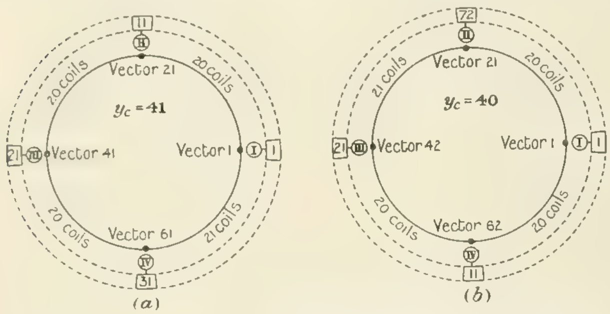


FIG. 34.—Phase Tappings for 4-phase Wave Winding.
$a = 1$; $p = 2$; C = 81.

Alternative (*b*).—Take $y_c = 40$ and split up the winding into groups of 20, 21, 20, and 20 coils respectively. The bars to be tapped then correspond with vectors 1, 21, 42, and 62 [see Fig. 34(*b*)].

Vector 1 = bar 1,
,, 21 = ,, $1 + 40 \times 20 = 1 + 71 = 72$,
,, 42 = ,, $72 + 40 \times 21 = 72 + 30 = 21$,
,, 62 = ,, $21 + 40 \times 20 = 21 + 71 = 11$,
(,, 1 = ,, $11 + 40 \times 20 = 11 + 71 = 1$).

Thus phases or slip-rings I, II, III, and IV go to bars 1, 72, 21, and 11 respectively.

It is seen that in both *a* and *b* the relative position of the bars on the commutator is practically the same.

Example 2.—An 8-pole wave winding has 4 circuits, 354 commutator bars, and 118 slots. Find the position of 3-phase tappings.

$$\text{Commutator pitch } y_c = \frac{C \pm a}{p} = \frac{354 \pm 2}{4} = 88 \text{ or } 89.$$

Symmetry conditions $p/a = 4/2 = 2$; $s/a = 118/2 = 59$;

these are whole numbers. Also $C = s\,u/2 = 118 \times 6/2 = 354$, *i.e.* no idle coils. The winding is symmetrical. Equipotential pitch : $y_p = C/a = 354/2 = 177$. There are two identical polygons, each of 177 sides, in the vector diagram. $m = C/a\,N_p = 177/3 = 59$; hence all three phases are alike, and the bars to be tapped have the same numbers as the vectors in the diagram, though possibly interchanged. The tappings can therefore be at once written down—

Phase I, tap coils n = 1, and $178 = n + y_p$,
,, II, ,, $n + m$ = 60, and $237 = (n + m) + y_p$,
,, III, ,, $n + 2m$ = 119, and $296 = (n + 2m) + y_p$.

The figures in the first column refer to bars in the first pair of circuits, and those in the second column to bars in the second pair of circuits. It will be noticed the latter are found by adding y_p to the numbers in the first column.

It may be interesting to confirm these positions for the phase tappings and to see how they are affected by the commutator pitch.

Let $y_c = 89$. Then C and y_c have no common factor > 1, so that the winding is singly closed. The diagram for this case is shown in Fig. 35(*a*), where for the sake of clearness

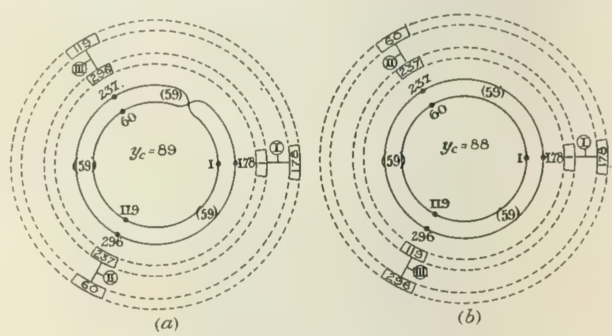


FIG. 35.—Phase Tappings for 3-phase Wave Winding.
$a = 2$; $p = 4$; C = 354.

the two polygons are drawn to different scales. The bars to be tapped must correspond with the vectors 1, 60, 119, 178, 237, and 296.

Vector 1 = Bar 1 —o I
" 60 = " $1 + 59 \times 89$ (= 295) = 296 —o II
" 119 = " 296 + 295 = 237 —o III
" 178 = " 237 + 295 = 178
" 237 = " 178 + 295 = 119
" 296 = " 119 + 295 = 60
(" 1 = " 60 + 295 = 1)

It is seen that the numbers of vectors and bars of phases II and III are interchanged.

Let $y_c = 88$. Then the highest common factor of y_c and C is 2, so that each polygon closes on itself and the winding is doubly closed. The diagram is shown in Fig. 35(*b*), and the vectors have the same numbers as in Fig. 35(*a*), but the corresponding bars are interchanged. Thus—

Vector 1 = Bar 1 —o I
" 60 = " $1 + 59 \times 88$ (236) = 237 —o II
" 119 = " 237 + 236 = 119 —o III
(" 1 = " 119 + 236 = 1)
Vector 178 (1+y_p) = Bar 178
" 237 = " 178 + 236 = 60
" 296 = " 60 + 236 = 296
(" 178 = " 296 + 236 = 178)

pleted. The other half is joined up in the same manner, and put in series or parallel with the first half, as needed.

... ues of q and Q. Thus the ripple due to the ... harmonics may be very pronounced, and this ... no electrical advantages over the corre-

... and the six terminals thus obtained can be interconnected ...

... pressure. The spread of the winding when opened in this way, however, is not altered, and the phases still overlap. On the other hand, if the winding is opened at ...

... must then be cut at the joints corresponding with ...

These joints are marked in Fig. 36(b), where the two ends of each of the three phases are shown. In Fig. 37 four different methods of connecting the three phases are shown, the most common being that shown in Fig. 36(b), which gives the highest pressure.

Sometimes it is more convenient to specify the coil-sides and their position in the slots, instead of the joints to be opened, in the shop's instructions. This is also very simple. Numbering all coil-sides in the top layer odd and the corresponding coil-sides in the bottom layer even, as in Fig. 29, then corresponding with bar or joint x, the number of the coil-side in the top layer is $(2x - 1)$ and in the bottom layer $(2x - 1) - y_f$. This can be seen from Fig. 33, for—

Bar 1 goes to coil-sides	1	and	$1 - y_f$
„ $1 + y_s$ „	„ $1 + y_s$	and	$1 + y_s - y_f$
	$= 1 + 2y_c$	and	$1 + 2y_c - y_f$
„ x „	„ $(2x - 1)$	and	$(2x - 1) - y_f$

Arranging the cross connectors for the two halves of each phase in series—

Opened joint x		Coil-side in top layer $2x-1$		Coil-side in bottom layer $(2x-1)-y_f$
1	I_s	1		134
23		45	III_f	20
45	II_s	89		64
67		133	I_f	108
10	III_s	19		152
32		63	II_f	38

The back pitch y_f is taken as 25. The positions of these coil-sides in the slots can be at once written down by remembering that the coil-side $u\,n$ is the last coil-side in slot n. Frequently a dummy coil has to be used in the ordinary wave winding, and the position of this coil must be borne in mind when fixing the position of coil-sides in the slots. If the idle coil is placed at the end of the winding, it is often possible to cut the winding at points which avoid it altogether, by merely choosing the groups of coils in the vector diagram [Fig. 36(a)] in the right manner. In this case the position of the coil-sides in the slots can be at once determined without reference to the idle coil.

It is hoped that these examples will show the advantages of the vector diagram for windings. Not only does the diagram illustrate the pressure relations of the harmonics, but the diagram for the fundamental affords a clear insight into the circuits and thereby provides a much simpler method of dealing with electrical problems than the actual drawing of the winding, which is both laborious and complicated.

Though outside the scope of this paper, it might also be added that the same simple method can be adapted for studying the effect of the number and the width of the commutator brushes on the symmetry of the circuits of a commutator winding. For this purpose the bars are laid out in a straight line and numbered 1, $1 + y_c$, $1 + 2y_c$, etc.,

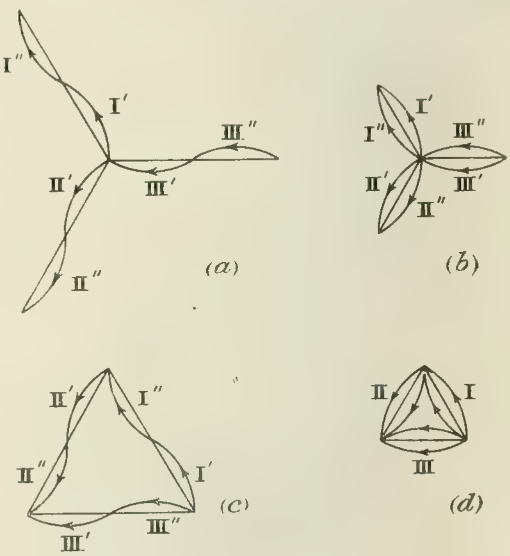


FIG. 37.—Different Connections with 3-phase Open Wave Winding.

whilst the bars making contact with the brushes are found by spacing the brushes correctly on the commutator circle. The circuits formed by the brushes can then be traced out at once on the developed commutator, and the dissymmetry caused by omitting brush spindles or using unsuitable brush-widths is made clear. Such a diagram explains well the cause of sparking and glowing in certain machines with symmetrical windings.

The author wishes to thank Mr. J. W. Sims for great assistance in preparing this paper, Mr. S. Neville for helping to draw up Table 9, and Mr. C. C. Hawkins for friendly criticism. The paper was written at the City and Guilds (Engineering) College.

DISCUSSION BEFORE THE INSTITUTION, 14 JANUARY, 1915.

Professor Silvanus Thompson.

Professor SILVANUS P. THOMPSON: Not only does this paper describe the present state of the subject, but it also includes the authors' investigations on many exceedingly interesting and novel points. The authors begin quite frankly by stating that they have not been concerned with assigning priority in connection with any one of the various points dealt with. When one who is presenting a subject finds that one of his predecessors has already thought of something that he himself has suggested, he ought to be pleased to know how the anticipation of his researches confirms their substantial importance. Those who have thought our thoughts before us ought not on that account to be underrated by us. We should be glad to confirm our own work by that which is already known. Prof Silv Tho I do not propose to touch on the questions of priority or history. No doubt in the works of Pichelmayer and Arnold, and of American writers such as Adams and Foster, many of these things have been expounded in various ways at different times. It is 10 years ago, for example, since at a Students' meeting of this Institution Messrs. Biedermann and Sparks* gave an account of the way in which the harmonics of an alternator could be reinforced or suppressed by certain spacings of the coils or by a certain choice of the breadth of pole. One is glad

* E. A. BIEDERMANN and J. B. SPARKS. E.m.f. wave-forms. *Journal I.E.E.*, vol. 35, p. 493, 1905.

[illegible] the references. For instance, in a reference to ripples due to spacing, one ought to know whether it refers to the [illegible] invidious, I want to make one little protest. I do not like [illegible] which might be avoided, in the use, [illegible] but one of the two pole-horns at the sides of the pole. [illegible] I wish that all writers on [illegible] practice. The result is that throughout nearly all the [illegible]ations it is continually necessary to refer to "$2p$" [illegible] the number of poles. Then there is "q." I thought [illegible] it may be very good, and that is the [illegible] word "circuit." The new definition [illegible] there were a number of similar loops or [illegible] a little consideration before one can [illegible] may be very good. There is one little

[illegible] forth it is p[illegible] what is the [illegible] gap in different parts, or in the case of the non-salient pole [illegible] crease the flux density in the middle. One form accom-[illegible] upon the reluctance of the air-gap. After all [illegible] poles. [illegible]

Professor Silvanus Thompson.

There are numbers of them. There are five of the first kind alone on page 214 and five of the second kind; and there are 12 more of them on page 229. I refer to this because it seems to me there is a possibility of facilitating future labour, as well as explaining what we are already doing when we use formulæ of these two kinds. Mathematicians are generally so busy with their own intellectual problems that they do not condescend to the needs of us who work with mathematics as a tool. A great many much more complicated expressions than those have in time past been simplified by the mere device of tabulating values. We have had tables of all the different functions, sines, cosines, and tangents of angles for several hundred years; we have our logarithms, natural and common, tabulated. Dr. Kennelly has tabulated various hyperbolic quantities for use in cable and transmission work. Gamma functions and Bessel's functions and elliptic functions, and spherical harmonics have been tabulated because the engineers and physicists wanted them and could not get on without them. Now my suggestion is this, that we ought really to give names to these new functions and tabulate them. We have had to do it bit by bit in other directions. I have been using small tabulations for things of this kind for some time in a very imperfect way without having special names for them. I am going to suggest to-night—because I think the authors will be glad of some kind of "handle" for these things—that we should call them by definite names. The names do not matter so long as we have a handle for them. What is the physical meaning, first of all, of $\frac{\sin\theta}{\theta}$? I want to suggest that its real physical meaning is this: Suppose we have a line of a certain length, and we stand it up on end and then tilt it over through an angle and drop a plumb line down from it, then the length of that plumb line divided by the sloping line is, as we all know, the cosine of the angle between; the cosine is the measure of the resolved height of this tilted-over line. If instead of having a tilted line we have an arc struck from some centre, it also is in a certain sense tilted over, although it begins by being straight; and if a plumb line is dropped from it we have, so to speak, between the plumb line and the curved arc a similar sort of relation. The sine of θ divided by θ is this curvilinear cosine. Just as we can get the resolved part of a sloping line by multiplying it by the amount it rakes over, so we get the function $\frac{\sin\theta}{\theta}$ by dividing the length of the plumb line by the length round the arc. That is its physical meaning, and I propose to call that function by the name of "cursine," and write it cursin θ. The other function $\frac{\sin n\theta}{n\sin\theta}$, which comes again and again in the paper, I propose to call by the name "persine," and write it pers$_n$ θ. I started tabulating these quantities years ago, and I found only this week that my chief assistant, Mr. J. K. Catterson-Smith, had been using a similar partial tabulation of the values of the cursine for the purpose of dynamo design. In particular he has found that the speed of running of an alternating-current commutator motor is always equal to the synchronous speed multiplied by unity plus some constant times the cursine of an angle, the angle depending upon the way that the brushes are set. I could mention various other cases—there are many, for instance, in the geometry of polygons and in certain methods of harmonic analysis—where a tabulation of these functions would be extremely useful to us. The Tables appended show a few of the figures of the tabulation. When we have these functions properly tabulated considerable labour will be saved to those who are working on these lines. Having given this suggestion to the authors, I should like to repeat my appreciation of the value of this paper in giving us a rational and fairly complete account of the state of the art, including their own investigations. My only regret is that the present paper stops short with the no-load conditions. It does not deal with the additional matters that come in to distort the curves of the flux when the machine is working at loads of different amounts and phases. I hope that the authors will be able to deal with that on another occasion.

Finally, nothing could emphasize better than a paper like this the very great value to the industry as a whole, and to those who are working at the design of machines, of the invention which enables us to see what the ripples really are. To M. Blondel, who first of all worked out the idea of the oscillograph, and to Mr. Duddell, to whom we owe so largely its realization, this paper must have a most extraordinary interest, for it shows what a useful tool an oscillograph is in enabling us to get at the complicated facts that need explanation.

TABLE I.

Values of cursin $\theta = \sin\theta \div \theta$.

θ	cursin θ	θ	cursin θ
0°	1 0000	90°	0·6381
10°	0·9949	100°	0·5643
20°	0·9798	110°	0·4895
30°	0·9549	120°	0·4135
40°	0·9207	130°	0·3376
45°	0·9003	140°	0·2631
50°	0·8778	150°	0·1910
60°	0·8270	160°	0·1225
70°	0·7691	170°	0·0585
80°	0·7053	180°	0·0000

TABLE II.

Values of $\mathrm{pers}_n\,\theta = \frac{\mathrm{cursin}\,n\theta}{\mathrm{cursin}\,\theta} = \frac{\sin n\theta}{n\sin\theta}$.

θ	$n = 2$	$n = 3$	$n = 4$
0°	1·000	1·000	1·000
10°	0·984	0·959	0·928
15°	0·966	0·909	0·836
20°	0·944	0·844	0·721
30°	0·867	0·663	0·431
45°	0·707	0·333	0·000
60°	0·500	0·000	— 0·250

Mr. H. BURGE: The authors appear to have arrived at some valuable conclusions, which I think, however, are somewhat obscured by an excess of mathematical detail. One gathers that in order to avoid ripples in windings

[illegible] n that of the authors, inasmuch as he [illegible]

[illegible] it lends itself better to the [illegible]

[illegible] winding in a single layer with coils [illegible]

[illegible] under one pole and one coil of the [illegible]

[illegible] and the designer may have done his best, but so long as even a small harmonic is present, there is just a [illegible]

[illegible] defect [illegible]

Mr. Hawkins.

waves appear side by side at o and two positive half-waves side by side at 3. For the fact that the E.M.F. wave can, and at least in some cases does pass through zero in the manner above described, there is experimental evidence. In actual cases the changes by flux-swing and by flux pulsation are very complicated, and it is difficult to isolate the one entirely from the other. There are other possible laws which the speed variation of the field might follow, and further analysis may show that they are actually more

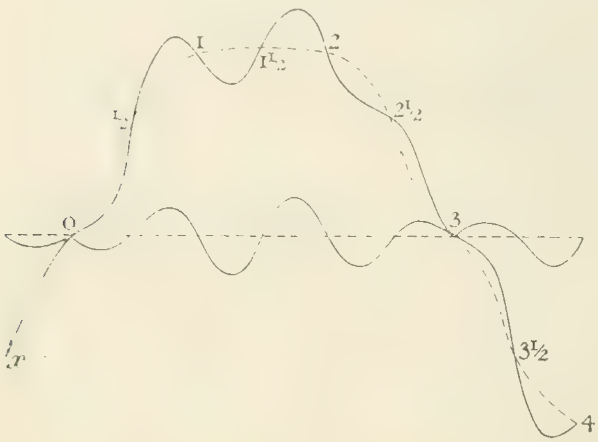


FIG. A.

true; but my point is that for flux-swing pure and simple, if at one end of the normal half-wave Fig. 19 correctly represents the facts, then it follows that at the other end the last half of a tooth-period must show an excess of electromotive force and not a deficit. A whole number of tooth ripples in the half period is then obtained, as required by the ordinary theory, and in the absence of this condition I venture to think that Fig. 19 cannot be held to be physically possible.

Mr. Everest.

Mr. A. R. EVEREST: I should like to class this paper with those to which Professor Thompson has referred, particularly the excellent one by Foster* about two years ago, and another American paper by Comfort Adams† about four years previously, which covered much of the ground with which the present authors deal; while a paper read in England by Mr. M. B. Field‡ a few years ago dealt with the question of the effect of the teeth in introducing ripples in the E.M.F. wave. To the best of my knowledge that was the first demonstration of the principles underlying the problem which has since been worked on by others. In view of the fact that these matters have been dealt with two or three times previously by other writers, I was a little disappointed to find there was no information in the paper regarding the relative practical success of the various methods adopted for accomplishing different purposes. I also regret that the authors have left the question of the effect of loads severely alone. I was rather hoping to find at least something about the effect of the circulating current in a closed delta armature, which is a distortion effect occurring without "load." Distortion in the flux wave is obtained if the machine is not perfect, due to the circulating current alone, and I should like to ask whether the authors cannot give us some information on that point. There is one remark in the paper which I think is very nicely put. The authors state: "Before a harmonic can appear in the pressure curve it must exist in the flux curve." That divides the whole problem into two very broad parts, one of which is the creation of the trouble due to irregularities in the wave of the flux from the rotor, and further distorted, as it may be, by the stator teeth; and the other is the elimination of the trouble by modifications of the winding. I cannot quite agree with the authors in their remarks as to the relative merits of the drum type of rotor compared with the salient-pole type. The type of rotor that is used is determined by a number of important principles, but the salient-pole rotor can be made to give a curve as near to a perfect sine wave as the drum type, and with the same degree of certainty. Reference has been made to staggering or "diagonaling" the poles with a view to eliminating troubles which have originated elsewhere. That, I think, is usually considered a very undesirable practice, at least in large alternators. It is done occasionally, but there are means of overcoming the difficulty by adopting special slot arrangements, which are usually considered preferable. There is one other point which the authors did not mention, and to which I should like to refer, namely, the effect of "amortisseur" slots in producing wave distortion. If the number of "amortisseur" slots in the field bears a certain relation to, or comes too close to, the number of slots in the armature, troubles arise on that account. In regard to harmonics being eliminated by the irregular slotting or irregular spacing of coils, this has been suggested several times, the first occasion being, I think, in 1903 or 1904. Punga then published in Germany an article in which he suggested that one or two slots should be left unwound. That suggestion is continually being made; but so far as I know, except for highly special work, it is not adopted in practice, for the very good reason that there are commercial manufacturing difficulties in applying it. Uneven spacing of the slots is obviously impossible on a large scale because all the slotting tools are set scrupulously for regular spacing. The other alternative, namely, winding with a fractional number of slots per pole is used, and that is a very good way of overcoming some of the difficulties. In that connection I should like to refer to the table on page 218 giving the harmonics for 3-phase windings with various numbers of slots per pole. In the first column, $q = 2$, that is there are 12 slots per pair of poles; the second column represents 18 slots; the third column, 24 slots; and the fourth column, 30 slots; but there are no figures given for intermediate values. If we apply the rule that was first laid down, so far as I know, by Mr. M. B. Field, we shall find that the frequency of the harmonics created by the slots is the number of slots per pair of poles plus or minus one. It is interesting to see what numbers of slots can be used which would make these become even numbers, because any number of slots which indicates harmonics of even number would give no working harmonics at all. That is found to be the case in practice,

* W. J. FOSTER. Potential waves of alternating-current generators. *Transactions of the American Institute of Electrical Engineers*, vol. 32, p. 749, 1913.

† C. A. ADAMS. Electromotive force wave-shape in alternators. *Transactions of the American Institute of Electrical Engineers*, vol. 28, p. 1053, 1909.

‡ M. B. FIELD. Study of the phenomenon of resonance in electric circuits by the aid of oscillograms. *Journal I.E.E.*, vol. 32, p. 647, 1903.

[illegible]

Dr. G. W. O. Howe: [illegible] unsatisfactory since, in comparison with the other parts of [illegible] when reading the paper Dr. Smith carried his indecision a step further and showed an alternative figure* with the tooth ripple unsymmetrical, and frankly admitted that he [illegible] appointing to me, since the authors originally had this figure [illegible] ripple must be symmetrical. Dr. Smith is evidently still [illegible] thinks that the correct figure has been cut out and the [illegible] symmetrical about its mid-point, the E.M.F. wave will pass through zero when the pole is exactly in the middle of the coil as shown in Fig. B [illegible] exactly opposite the centre of a tooth or of a slot. If, now, the pole is moved slightly either to the right or to the left, the change in the flux through the coil will be the *same* both in magnitude and direction, and therefore the electromotive force induced in the

* See Fig. [illegible]

[illegible]

Fig. A. Fig. B.

[illegible] correct, and [illegible] a tooth-pitch. In the latter case there is no tendency for any fluctuation in the flux per pole, and the flux in a tooth [illegible] total flux per pole will be prevented from fluctuating to any great extent by the currents induced in the poles and magnet ring, unless these are laminated, and also in the [illegible]

* [illegible]

Dr. Howe is not present when the machine is rotated slowly, and which would not be shown by an exploring coil wound round a tooth and connected to a ballistic galvanometer or flux-meter, unless the total flux per pole were always adjusted to have the same value. We have therefore three cases: (1) The air-gap reluctance is constant; (2) the air-gap reluctance fluctuates and causes a corresponding variation in the total flux; and (3) the air-gap reluctance fluctuates, but the total flux is maintained practically constant by induced currents. In the first case ripples will be produced with their maximum amplitude at the peak of the E.M.F. wave, as shown in Figs. 19 and 20. In the second case, which is very rare, ripples will be produced, having their maximum amplitude as the E.M.F. wave passes through zero. In the third case, the ripples will be reduced in amplitude. The reason of this may be seen from Fig. C. As the North pole moves to the right it will introduce flux into the coil at an irregular rate as the pole-tip passes successively teeth and slots. If the air-gap reluctance is constant the receding South pole will remove its flux in the same irregular way, and will accentuate the irregularities, giving rise to pronounced ripples. If, however, the air-gap reluctance is not constant, but the total flux is maintained constant, then the advancing North pole will cover an extra tooth without uncovering one behind it, the gap reluctance will be thereby decreased, and in order to maintain the total flux constant the flux per tooth will be decreased. Hence we have two opposing tendencies—the sudden increase of the flux through the coil, due, first, to the advancing North pole covering another tooth, and secondly to the decrease in the flux per tooth under the South pole, being counteracted to some extent by the decrease in the flux per tooth under the North pole. This will lead to a reduction in the amplitude of the ripples, and would appear to be the most favourable condition. It is to be noticed, however, that although in the second and third cases the irregularity in the phase of the ripple occurs at the peak of the main wave and not at its zero point, yet in every case the ripples are quite symmetrical with respect to the main wave. In answer to another objection raised by Mr. Hawkins with reference to Fig. 19, it should be pointed out that wherever the ripple has a well-pronounced frequency, its period is 1/18th of the fundamental, or its frequency is 18 times that of the fundamental. If one attempts to determine the ripple frequency by counting the number of crests or waves, one is always in some uncertainty at the zero point of the main wave, owing to the peculiar irregularity in the ripple at this point. To prevent anybody being misled by the arguments put forward by Mr. Hawkins, which led him to the conclusion that Fig. 19 is physically impossible, I may point out that his whole argument is based on the assumption, "if then there was excess of field speed and of electromotive force from ½ to 1, there must also, etc." This assumption is quite unwarranted and is inconsistent with the symmetry of the pole; if he assumed that the first half-ripple returned to the base line at ¼ and that the excess of electromotive force extended from ¼ to ¾, he would be led to an exactly opposite but correct conclusion. A convenient and simple way of studying tooth ripples is shown in Fig. D for the case considered by Mr. Hawkins, viz. 3 slots per pole and such an effective pole width that there is no change in the air-gap reluctance. If the effect of "fringing" is neglected, the electromotive force Dr. Howe is as shown at *b*, where the dotted line is Mr. Hawkins' "smoothed-out wave." The difference between them is

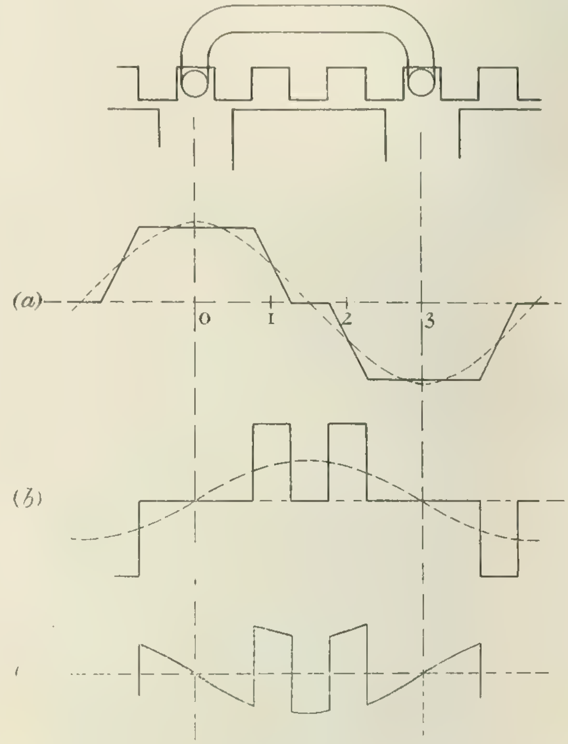


FIG. D.
(*a*) Flux through the coil.
(*b*) Electromotive force induced in the coil.
(*c*) Ripple only.

shown at *c* and may be called the ripple. Fringing from pole-tips and teeth will reduce the amplitude of the ripples and round them off, without, however, in any way altering their phase or destroying their symmetry with respect to the E.M.F. wave.

Mr. R. G. JAKEMAN: The authors are to be specially Mr. Jakeman congratulated on the remarkable way in which their calculated wave-forms agree with the actual oscillograms. Figs. 7 and 8, Fig. 9, and Figs. 11, 12 and 13 show this agreement very clearly. Fig. 9 seems to me to be especially interesting; it shows that, by careful design, any wave-shape whatever may be obtained without difficulty. The authors inform us that in the case of a non-salient-pole turbo-alternator with the polar-hump unslotted, with a flux curve like that in Fig. 9, the phase pressure will have a 5 per cent third harmonic. This, of course, is very serious if the neutral point is earthed, and I should like to know whether the authors have any oscillograms which show this harmonic. Turning to Part II, the use of extra empty slots in order to suppress the higher harmonics seems to give very satisfactory results. The advantage can be seen at once on comparing Table 3 on page 218 with Table 9 on page 230. The figures given by the author, however, do not seem to be quite practical, since it is impossible to put one or two extra slots in anything but a single-phase generator. Three-phase generators must have at least three extra slots and 2-phase machines at least four, because otherwise the phase pressures become shifted and no

[illegible] ber of [illegible] danger of producing tooth ripples. In [illegible] slots, so that in a 6-phase converter the angles between the tappings will not be accurately 60°, or in a 4-phase [illegible] winding tables. If so, I think some further details would [illegible]

[illegible] complex in wave-form, is analysed into its harmonics, then the electromotive forces induced in the winding by each [illegible] It is easy [illegible] but I shall only show it briefly for the case of the coil-span factor. To do this I replace the special Equation (4) in the [illegible]

[illegible]

Mr. Chapman. a very comprehensive treatment of pressure waves from the designer's point of view. I was glad to find that the authors emphasize the importance of symmetry in the design of windings. My chief objection to the vacant-slot method of suppressing the tooth and spacing ripples arises from the dissymmetry introduced thereby. In the case of polyphase alternators the presence of a vacant slot causes the phase differences between the electromotive forces of the several phases to be unequal. The example on page 229 represents, perhaps, a somewhat extreme case, but the angles between the three phases there would be 115°, 115°, and 130°. In view of the sensitiveness of induction motors and rotary converters to any inaccuracy in the supply pressures, I think it is as well that attention should be drawn to this point, which might be serious in some instances. If the number of poles is not divisible by three, the introduction of three empty slots, placed symmetrically, will not produce this dissymmetry in a 3-phase machine. A similar effect frequently creeps in with double-layer windings. This will not be detected if the vector polygons are built up on the basis of the average value of ψ_c as recommended by Dr. Smith. Consider, for instance, the example on page 234. Since there are eight coil-sides per slot the coil vectors will be in groups of four; each group making up one side only of the complete vector polygon, and as each phase contains 14 coils in series the phase pressure will be represented by a line joining one corner of the polygon to the middle of the fourth side. The winding is thus not truly 6-phase, the angles between successive phases being 58° 48′ and 61° 12′ alternately. If windings of the type shown in Fig. 29 (*b*) had been employed, the number of sides in the vector polygon would have been doubled and the inequality between the phase angles would have been removed. In the case of wave windings the more accurate diagram will usually be an irregular polygon and the phase vectors will be more or less inaccurate in all cases except those of a very limited class. Although small deviations may not be of serious importance in many cases, the designer may get into trouble through them if he does not foresee the possibility of their occurrence.

Mr. Broughton. Mr. H. H. Broughton (*communicated*): The amount of work that has been done on this subject (apart from that to be found in the paper) is considerable, and no doubt the authors have an extensive bibliography at hand. I am of the opinion that such a bibliography, as an appendix to the paper, would be useful to other workers in the field. I take it that a designer's object is to produce a machine which will give a sinusoidal wave. Close attention is paid by designers to the shape of the slots and pole-shoes, and encouraging results have been obtained by skewing the latter. If the authors, in their reply, would briefly set forth the steps to be followed in order to secure a sinusoidal wave I should be obliged to them. Some years ago Rüdenberg discussed the question of suppressing all the more prominent harmonics, even in cases where the flux distribution was extremely irregular, by a suitable distribution of the winding. Rüdenberg gave as examples a number of windings as well as the oscillograms of the pressure waves obtained with various flux distributions. An inspection of those oscillograms shows that many of them are practically sinusoidal, and in some cases the important harmonics are entirely eliminated. I should like to know whether the authors have had an opportunity of making tests on an alternator wound in that way. If they have made such tests, do the results compare favourably with those obtained by Rüdenberg? It is, or it should be, common practice to specify the shape of the pressure wave in electrical machinery, and in those cases where it is desired quickly to determine the departure from a sinusoidal wave I think that two no-load ammeter-voltmeter readings, one with a choking coil and condenser in circuit, and the other with the condenser alone, would prove satisfactory. Although such a test gives no idea as to which harmonics are distorting the wave, it gives an excellent idea of the combined effect of the harmonics, and that is useful information. I have used the method on several occasions when no oscillograph was available to check the purity of the wave, and I have found it convenient and practical. Mr. Broughton.

Messrs. Smith and Boulding. Messrs. S. P. Smith and R. S. H. Boulding (*in reply*): We should like to explain that the paper is intended to form as far as possible a complete and objective study of the whole problem within the limits stated. Though questions of priority had to be disregarded, claims to originality were treated in the same way. Also reference to the work of many of the writers mentioned by speakers would have served little purpose, except for comparing results here and there.

The oscillograms were collected during several years of practical experience, and the results were collaborated and worked out at the City and Guilds (Engineering) College in connection with the post-graduate course in electromagnetic machinery under Professor Mather. This is the first Institution paper produced in this course of the Imperial College of Science and Technology, and it is hoped that further papers of a similar nature will follow in the future.

However desirable the discussion of special windings, load conditions, and of the other points raised might be, it was not found possible to deal with more than the standard single-layer and double-layer windings under no-load conditions, for reasons which were clearly stated at the outset of the paper. It might be mentioned that load conditions are now being investigated. Further, the objective standpoint maintained throughout the paper must be emphasized, and it must not be assumed that we advocate any particular form of construction such as the salient-pole or non-salient-pole rotor, or the use of empty or skewed slots.

The question of the phase of the tooth ripple due to the swinging of the flux (see Section 4) was intentionally left open for discussion. Originally Fig. E (reproduced herewith) had been drawn for the paper, and certain oscillographic evidence appeared to confirm the correctness of this diagram. Later, however, the correspondence in the *Electrician* (referred to on page 224) led us to reconsider the matter, and we came to the conclusion that Fig. 19 was more likely to be correct, both from considerations of symmetry and from inspection of oscillograms. Mathematically, Fig. 19 is obtained by making $\xi = 0$, whilst for Fig. E $\xi = \gamma/4$. Since, in our opinion, no convincing arguments on these points had been published, it appeared advisable therefore to provoke a discussion in order that this question, which is not without theoretical interest, might be thrashed out.

[illegible]

[illegible]

[illegible] the effects of the stator and the rotor teeth, provided it is [illegible] able ; nor is the term "hump," for [illegible] Circuits in a winding are not necessarily [illegible] though it is emphasized that with parallel connec- [illegible] be distorted on load. In practice it is [illegible] of chamfering the pole-tips. Of course with the non-salient-pole rotor, slotted uniformly over the whole periphery, the nearest approach to the ideal is obtained. The argument

[illegible] mathematically [illegible]

[illegible] in order to prevent the formation of the tooth ripple is not [illegible] we lay special stress on the fact that when the number of [illegible]

[illegible] extra [illegible] three empty slots 120 [illegible] three extra slots in this way is to [illegible]

[illegible]

THE MAGNETIZATION OF IRON AT HIGH FLUX DENSITY WITH ALTERNATING CURRENTS.

By J. S. NICHOLSON, B.Sc., Associate Member.

(*Paper first received 28 July, and in final form 9 October, 1914; read before the* SCOTTISH LOCAL SECTION 8 *December*, 1914.)

In the testing of iron stampings at high flux densities by means of alternating currents great difficulty is experienced in maintaining an electromotive force of sine-wave form at the terminals of the magnetizing winding, and in ensuring that the electromotive force induced in the windings of the tester shall also be of sine-wave form.

If the induced electromotive force varies according to a simple sine function of the time, namely $e = E \sin 2\pi f t$, where e = instantaneous value of the electromotive force, E = maximum value of the electromotive force, and f = frequency, then the flux density in the core of the tester will also vary according to a simple sine function of the time, or $B = B_m \sin (2\pi f t + \pi/2)$, so that B_m, the maximum value of the flux density, can be obtained in the usual way from the induced electromotive force, E_i, and the number of turns, T, in the secondary winding, etc.

$$\begin{aligned} E_i &= 4{\cdot}44\, T f \Phi_m \times 10^{-8} \\ &= 4{\cdot}44\, T f B_m A \times 10^{-8} \end{aligned}$$

Therefore

$$B_m = \frac{E_i \times 10^8}{4{\cdot}44 \times T f A} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

and $B_m \propto E_i$ for a constant number of turns and constant frequency. If, however, the flux and therefore also the induced electromotive force do not vary in this way, it becomes difficult to ascertain, even approximately, the value of the maximum flux density in the core corresponding to a particular value of the induced electromotive force.

The author will show in what follows how at flux densities with maximum values of 20,000 lines per sq. cm. and upwards in "Stalloy" the flux in the tester core was approximately maintained as a simple sine function of the time.

SINGLE-PHASE ALTERNATING-CURRENT TESTER.

Some idea of the possible divergence of the wave-form of induced electromotive force from the simple harmonic form, and of the magnitude of the error in B_m when calculated from Equation (1), may be obtained by a study of the oscillograms reproduced in Fig. 1. These were obtained from a ring tester connected between two lines of a 40 k.v.a. star-connected 3-phase alternator giving an electromotive force of simple sine-wave form on open circuit. The magnetizing winding of the tester had 6 turns per cm. length of periphery, and the cross-section of the core (Stalloy) was 7·5 sq. cm. Oscillograms of E_t, E_i, and I were taken when the induced electromotive force in a search coil of 150 turns was 19·7 and 22·5 volts at 22·5 cycles per second, corresponding to values of B_m from Equation (1) of 17,500 and 20,000 lines per sq. cm. respectively.

The equation for the wave of induced electromotive force E_i is, however,

$$e_i = \sqrt{2}\, E_1 \sin \omega t + \sqrt{2}\, E_3 \sin 3(\omega t + \alpha_3) + \sqrt{2}\, E_5 \sin 5(\omega t + \alpha_5) + \dots \quad (2)$$

where $E_i = \sqrt{(E_1^2 + E_3^2 + E_5^2 + \dots)}$; and the equation to the flux wave is

$$\Phi = \Phi_{m1} \sin (\omega t + \pi/2) + \Phi_{m3} \sin [3(\omega t + \alpha_3) + \pi/2] + \Phi_{m5} \sin [5(\omega t + \alpha_5) + \pi/2] + \dots \quad (3)$$

where

$$\Phi_{m1} = \frac{E_1 \times 10^8}{4{\cdot}44\, T f}; \quad \Phi_{m3} = \frac{E_3 \times 10^8}{4{\cdot}44\, T \times 3 f}; \quad \Phi_{m5} = \frac{E_5 \times 10^8}{4{\cdot}44\, T \times 5 f};$$

and so on; and where

$B_{m1} = \frac{\Phi_{m1}}{A}$; $B_{m3} = \frac{\Phi_{m3}}{A}$; $B_{m5} = \frac{\Phi_{m5}}{A}$, etc., A being the cross-sectional area of the iron in sq. cm.

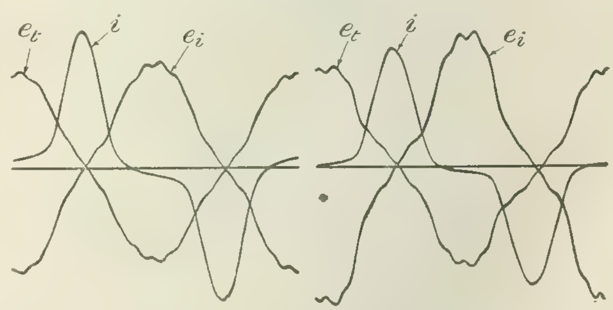


FIG. 1A. FIG. 1B.

Oscillograms of e_t, i, and e_i.

B_m (apparent) = 17,500 and 20,000 lines per sq. cm. respectively.

On analysing the above curves of E_i it will be found that $\Phi_m \doteq \Phi_{m1} - \Phi_{m3} - \Phi_{m5}$ for Figs. 1A and 1B, giving therefore the following values for B_m (actual) in the Stalloy cores.

B_m apparent number of lines per sq. cm.	E_i in 150 turns Volts	E_1 volts	E_3 volts	E_5 volts	$\frac{E_i - E_1}{E_i}$	$\frac{\Phi_{m3}}{\Phi_{m1}}$	$\frac{\Phi_{m5}}{\Phi_{m1}}$	Correction for B_m (apparent)	$\frac{B_m \text{ (actual)}}{B_m \text{ (apparent)}}$	B_m (actual)
17,500	19·7	19·58	2·04	0·62	0·006	0·035	0·006	0·047	0·953	16,600
20,000	22·5	22·06	4·46	0·68	0·020	0·067	0·006	0·093	0·907	18,100

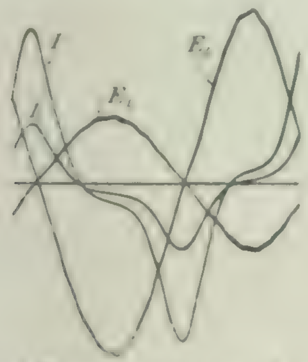
[illegible]

[illegible]

[illegible] to decrease.

[illegible]

The divergence of the terminal electromotive force from [illegible] ng current.



[illegible]

[illegible] tester. [illegible] of the [illegible]

[illegible]

this harmonic, and (2) because it is, next to the fundamental, I_1, the most important component. The other components, I_5, I_7, etc., of frequencies $5f$, $7f$, etc., are of minor importance.

A simple method of isolating I_3 and of limiting the magnitude of the electromotive force, E_3, necessary to produce I_3 is illustrated in Fig. 4. The magnetizing windings, A, are supplied with currents, I_A, from a star-connected 3-phase alternator giving a sine-wave electromotive force on open circuit. The currents, I_A, will have no third harmonics, but they will include the 5th, 7th, 11th, etc., harmonics. The D windings, being mesh-connected, can only carry currents of triple frequency, or multiples thereof.

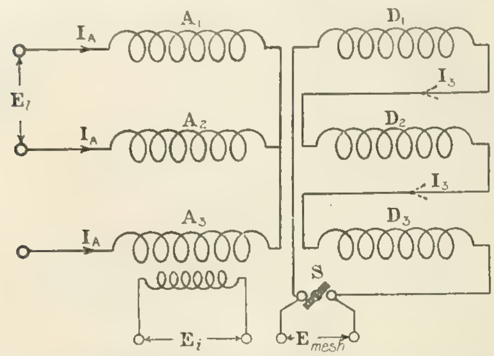


FIG. 4.—Three similar Ring Testers each with two Magnetizing Windings, A and D, uniformly distributed. The A Windings are Star-connected and the D Windings Mesh-connected and Short-circuited.

Case 1. *Switch S, in mesh windings D, open.* (*Fig.* 4.)—The magnetizing current has no triple harmonic, and hence the flux in the cores of the testers cannot vary according to a simple harmonic law but will have a pronounced third harmonic. The electromotive force induced in a search coil on any of the testers will therefore have a strong triple harmonic, E_3, the value of which will be one-third of the resultant electromotive force on open mesh.

The results of a test at 22·5 cycles per second with open-circuited mesh are given in the following table:—

this producing a flux which is very approximately of simple harmonic form. The resultant mesh voltage, $3\,E_3$, becomes very small, since it is now approximately equal to $I_3 \times 3\,r_D$, where r_D is the resistance per phase of the windings D.

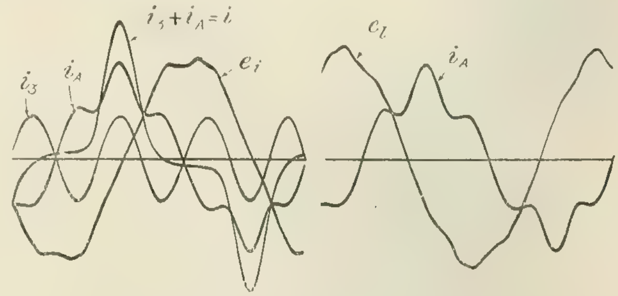


FIG. 5A.—Oscillograms when B_m (apparent) = 17,500.

Oscillograms of I_A, I_3, I, E_i per phase, and E per line of 3-phase alternator, are given in Fig. 5, and a few of the results of a test at 22·5 cycles per second are given in the table on page 251.

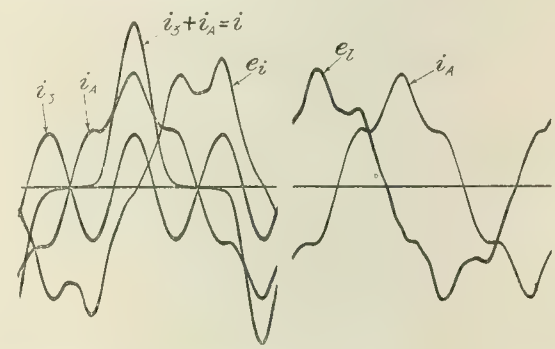


FIG. 5B.—Oscillograms when B_m (apparent) = 21,000. Connections of Circuit as in Fig. 4 with Mesh Short-circuited.

For a given flux density, E_i is proportional to the frequency, whilst E_3 being proportional to I_3 ($E_3 \doteqdot I_3 \times 3\,r_D$) is therefore dependent on the flux density and almost independent of the frequency. At higher frequencies, therefore, the ratio E_3/E_i will become smaller and the triple harmonic component in E_i will be negligible.

$\sqrt{E_1^2 + E_3^2 + E_5 + \dots} = E_i$ volts	$E_3 = E_{mesh}/3$ volts	I_A amperes	$\sqrt{E^2 + E_5^2} \doteqdot E_1$ volts	$\frac{E_3}{E_i}$	$\frac{E_3}{E_1}$	Remarks
34·5	19·2	41·5	28·7	0·557	0·668	
30·6	16·8	18·75	25·6	0·549	0·656	See Fig. 4. Test at 22·5 cycles per second,
25·9	14·1	6·1	21·7	0·545	0·650	E_i, E_3, etc. Volts in 150 turns per phase,
19·9	9·54		17·45	0·480	0·547	I_A Amps. in 6 turns per cm.
10·5	4·15		9·65	0·395	0·430	

Case 2. *Switch S, in mesh windings D, closed.* (*Fig.* 4.)—The resultant mesh voltage, $3\,E_3$, will now send a current, I_3, of triple frequency round the mesh circuit. This secondary current, I_3, and the primary current, I_A, combine to give a total magnetizing current, $i = i_A + i_3$,

The greatest drawback to measurements of the iron losses with the above connections (Fig. 4) is the fact that the copper losses in the mesh circuit soon greatly exceed

[illegible]

[illegible]

induced electromotive force, and also avoid the determina- [illegible]

and magnitude. The resulting current, I_3, is then adjusted [illegible]

I_4, in the star-connected windings until the resultant [illegible]

results have been obtained.

[illegible]

the insuline and the scale accounting for the [illegible]

Mean thickness of each stamping = [illegible]

The core rings were bound firmly together with tape.

[illegible]

METHOD OF CARRYING OUT THE TEST.

[illegible] ring-wound rotary converter which was coupled to a 2-

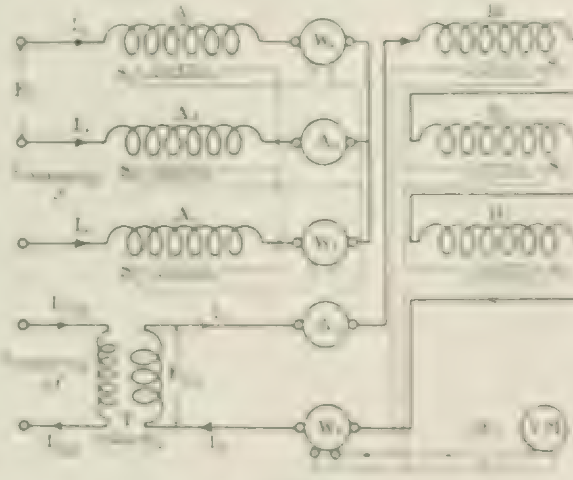


FIG. 6.

[illegible]

pole synchronous motor supplied with power from the 3-phase alternator. The single-phase current, I_3, was taken from one of the three phases of the rotary converter and the final phase adjustment of I_3 relative to the 3-phase current, I_A, was made by loading slightly the remaining two phases of the rotary converter with a lamp load, or by adjusting a variable inductance in series with the transformer, T. The step-down transformer, T, kept the voltage of the rotary converter high and its current low, thereby reducing the armature reaction and maintaining a sine-wave electromotive force, E_{t3}, at the terminals of the mesh circuit. The ratio, n, of this transformer, T, varied from 5 at the highest saturation to 20 at the lower values of the saturation.

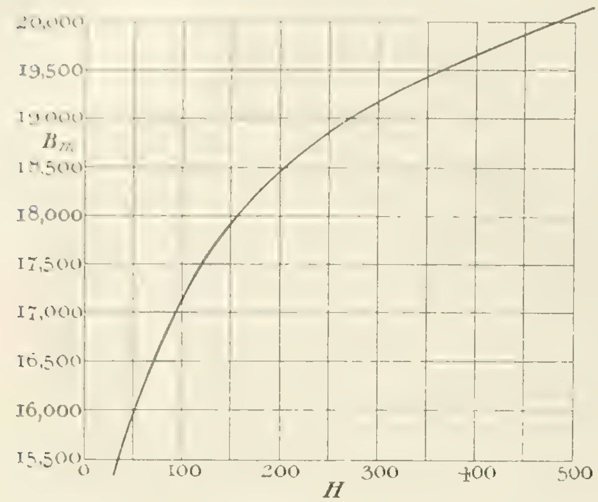


FIG. 7.—B-H Curve for Stalloy Core.

The phase and magnitude of I_3 were correct when the voltmeter, V.M., and the wattmeter, W_3, each read zero. No difficulty was experienced in reducing the reading of V.M. ($3\ E_3$) to less than 1 volt with 150 turns in each of the mesh search coils, S_2, in tests carried out at a frequency of 22·5 cycles per second at the highest degree of saturation reached. The oscillogram reproduced in Fig. 10 shows that this electromotive force was mainly of frequency $9f$.

Wattmeter readings.—Each wattmeter had its moving system fitted with a concave mirror of 1 metre radius of curvature. Means were also provided for interchanging the two elements of the 2-phase wattmeter to eliminate errors due to slightly different constants of these elements.

Tests were carried out at 22·5 cycles per second and at 15 cycles per second, giving 67·5 cycles per second and 45 cycles per second respectively for the single-phase alternator. All the test results given are for temperatures of the Stalloy cores of 55° C. to 65° C.

RESULTS OF TESTS CARRIED OUT.

(*a*) *At 22·5 cycles per second, W_3 being adjusted to read zero.*

Induced E.M.F.'s		W_A. Total iron losses in cores	Apparent value of B_m in cores	Actual value of B_m in cores	$\frac{B_m \text{ (actual)}}{B_m \text{ (apparent)}}$	Remarks
E_t in 150 turns	$3\ E_3$ in mesh of 3×150 turns					
Volts	Volts	Watts	Lines per sq. cm.	Lines per sq. cm.		
24·86	0·75	56·4	22,100	20,800	0·941	
23·68	0·35	50·6	21,050	20,170	0·958	B_m (apparent). For determination of correction factor for B_m see p. 255.
22·54	0·15	45·1	20,040	19,440	0·970	
21·43	0·20	40·1	19,050	18,630	0·978	
20·3	0·20	37·3	18,040	17,750	0·984	

(*b*) *At 15 cycles per second, W_3 being adjusted to read zero.*

Induced E.M.F.'s		W_A. Total iron losses in cores	Apparent value of B_m in cores	Actual value of B_m in cores	$\frac{B_m \text{ (actual)}}{B_m \text{ (apparent)}}$	Remarks
E_t in 150 turns	$3\ E_3$ in mesh of 3×150 turns					
Volts	Volts	Watts	Lines per sq. cm.	Lines per sq. cm.		
16·57	0·80	34·5	22,090	20,570	0·931	
15·78	0·50	31·0	21,040	20,030	0·952	
15·03	0·20	27·8	20,040	19,340	0·965	
14·28	0·40	25·7	19,040	18,560	0·975	
13·56	0·10	23·85	18,080	17,740	0·981	

[illegible] magnetizing currents, I_a and I_b.

A [illegible]

[illegible] Fig. 7.

[illegible]

[illegible]

[illegible]

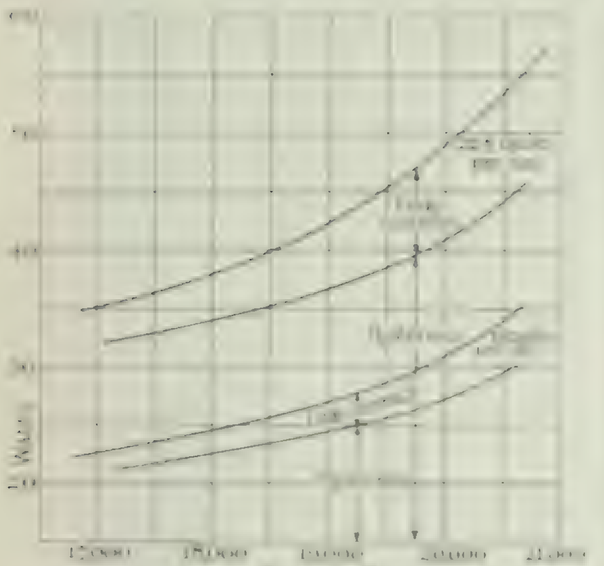


Fig. 8.—Stalloy Core Losses.

[illegible] hysteresis losses plotted against B_m are also shown in Fig. 8.

$$W_c = \text{hysteresis losses} + \text{eddy current losses}$$
$$= \eta V f B_m^x + \beta V f^2 B_m^2$$

where η and β are constants and V is the volume in cubic cm.

Therefore $\frac{W_c}{f} = \eta V B_m^x + \beta V f B_m^2$
$$= a + bf \text{ if } B_m \text{ is constant}$$

The index, x, of B_m in the hysteresis loss formula may now be determined as follows:—

$$a = \eta V B_m^x,$$
$$\log a = \log \eta V + x \log B_m$$

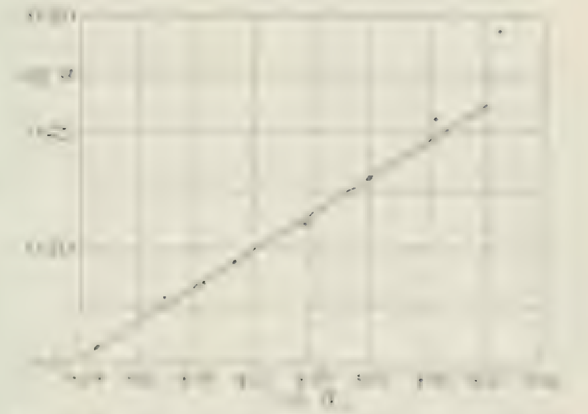
A graph with corresponding values of $\log a$ as ordinates and $\log B_m$ as abscissae is given in Fig. 9, and for values of [illegible]

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]

[illegible]



[illegible]

[illegible]

Oscillograms of current and electromotive force taken under the above test conditions are shown in Figs. 10A, [illegible] magnetizing-current wave.

[illegible]

The current, I_a, contains all harmonics of the magnetizing current except the triple harmonic and multiples thereof, thus

[illegible]

whilst the single-phase alternator current, I_3, will contain only the triple harmonics and multiples thereof,

$$i_3 = \sqrt{2}\, I_3 \sin 3\,(\omega t + \alpha_3) + \sqrt{2}\, I_9 \sin 9\,(\omega t + \alpha_9) + \ldots$$

The total current $i = i_A + i_3$,

$$= \sqrt{2}\, I_1 \sin(\omega t + \alpha_1) + \sqrt{2}\, I_3 \sin 3\,(\omega t + \alpha_3) + \sqrt{2}\, I_5 \sin 5\,(\omega t + \alpha_5) + \ldots$$

The oscillograms in Fig. 10 show a pronounced fifth harmonic in I_A, whilst I_3 is very approximately a pure

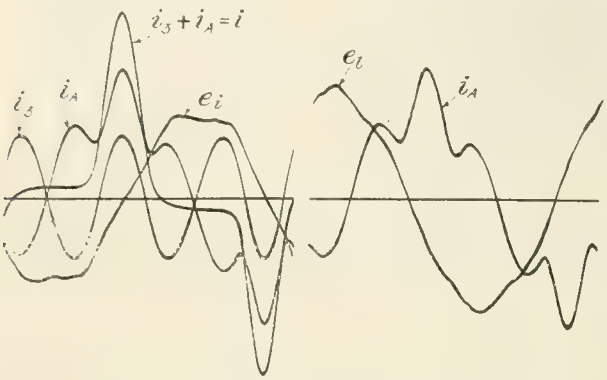


FIG. 10A.—15 Cycles per sec. ; $B_m \doteqdot 17{,}500$.

sine wave of triple frequency. The induced electromotive force, E_i, per phase of the tester begins even at the comparatively low maximum flux density of 17,500 lines per sq. cm. (Fig. 10A) to depart from the simple harmonic form, and at 21,000 lines per sq. cm. (apparent) a strongly pronounced fifth harmonic, corresponding to the fifth harmonic in I_A, is evident. In this case, however, the

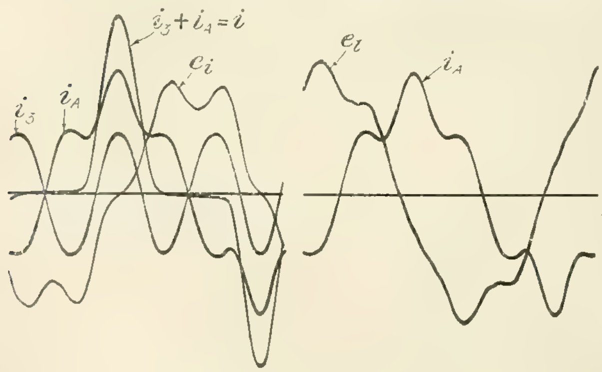


FIG. 10B.—15 Cycles per sec. ; $B_m \doteqdot 21{,}000$.

induced electromotive force, E_i, has no triple-harmonic components, and consequently the equation to this electromotive force wave may be written

$$e_i = \sqrt{2}\, E_1 \sin \omega t + \sqrt{2}\, E_5 \sin 5\,(\omega t + \beta_5) + \sqrt{2}\, E_7 \sin 7\,(\omega t + \beta_7) + \ldots \quad (6)$$

giving for the flux Φ interlinked with each search coil,

$$\Phi = \Phi_{1m} \sin(\omega t + \pi/2) + \Phi_{5m} \sin\{5\,(\omega t + \beta_5) + \pi/2\} + \Phi_{7m} \sin\{7\,(\omega t + \beta_7) + \pi/2\} + \ldots$$

A large number of oscillograms of E_i were analysed graphically, and the ratios, E_5/E_1 and E_7/E_1, obtained from the analyses are plotted against B_m (apparent) in Fig. 11.

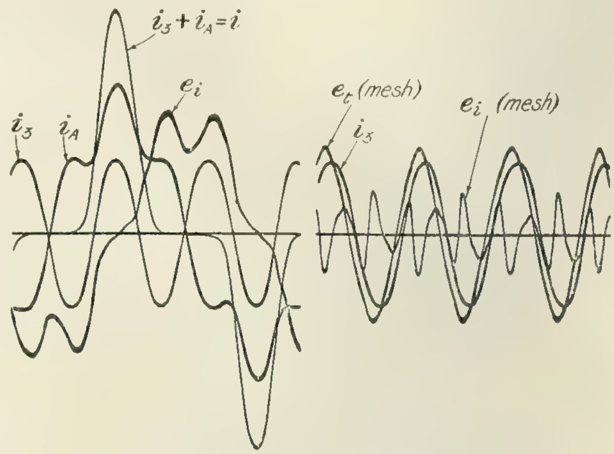


FIG. 10C.—22·5 Cycles per sec. ; $B_m \doteqdot 21{,}800$; e_i (mesh) is here shown greatly magnified. Connections as in Fig. 6.

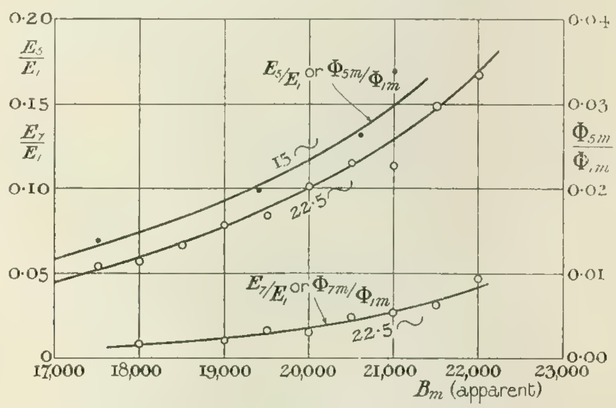


FIG. 11.—Values of E_5/E_1 and E_7/E_1 (see Equation 6) obtained by Analysis of Waves of E_i.

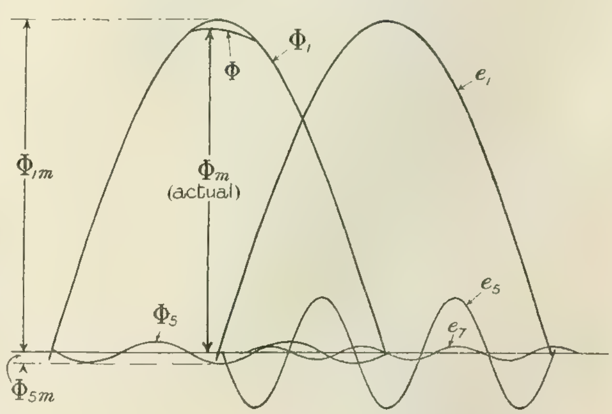


FIG. 12.—Analysis of the Wave of E_i shown in Fig. 10B.

At the maximum saturation reached in the Stalloy cores the ratio, E_5/E_1, did not exceed 0·160, and hence the maximum value of Φ_{5m}/Φ_{1m} did not exceed 0·160/5 or 0·032,

[illegible]

[illegible] in the wave of [illegible] [illegible]

[illegible]

[illegible] in this table :—

[illegible] Fig. [illegible]

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	0·75	0·8	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	0·50	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0·978	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	

[illegible]

[illegible] the interesting relations which hold between the various [illegible] the Stalloy cores ranging from 17,000 lines per sq. cm. to [illegible] in the [illegible] that the converse is more nearly true, viz. [illegible] current tend to diminish slightly as the flux density in-

[illegible] Fig. 13 were obtained.

[illegible] second were analysed graphically and gave the values of the various harmonics which are also plotted in Fig. 13 [illegible] ing force [illegible] are pro- duced in the circuit by electromotive forces induced in the

tester windings, and hence there is a distortion of the core flux from the simple harmonic form.

A similar result was obtained for the ratio I_3/I_A when the test connections were as shown in Fig. 4, with the mesh windings short-circuited, and the testers were forced to induce their own triple harmonics (see dotted line in Fig. 14). With these connections the ratio, I_3/I_A, decreased to 0·575 at the highest saturation, instead of only falling to 0·615 as was the case when I_3 was supplied from an external source. We may therefore quite reasonably assume that if the harmonics, I_5 and I_7, had also been supplied from external sources, the ratios, I_5/I_1 and I_7/I_1, would be increased at the higher flux densities and would become more nearly constant. Further, it is probable that under these circumstances the increased values of I_5 and I_7 would react on the triple harmonic, I_3, and cause it

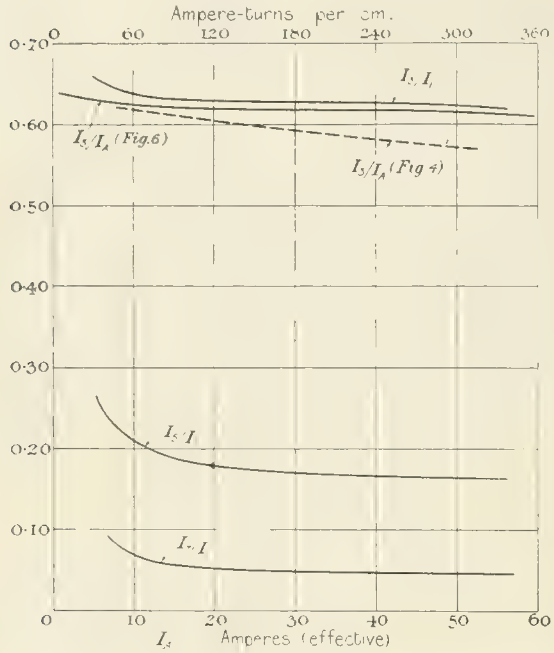


FIG. 14.—Ratios of Higher Harmonics of the Magnetizing Current to the Fundamental Components I_1 or to I_A for a Frequency of 22·5 Cycles per second, and with Test Connections as in Fig. 6.

and also the ratio, I_3/I_1, to be slightly increased at the higher flux densities.

The equation for the magnetizing current when B varies according to a simple harmonic law, $B = B_m \sin(\omega t + \pi/2)$ would then become

$$i = \sqrt{2}\, I_1 \{ \sin(\omega t + \alpha_1) + a_3 \sin 3(\omega t + \alpha_3) + a_5 \sin 5(\omega t + \alpha_5) + a_7 \sin 7(\omega t + \alpha_7) + \dots \} \quad (8)$$

where a_3, a_5, a_7, etc., are approximately constants when saturation is reached and have the values 0·63, 0·25, 0·10 (approx.), for Stalloy.

The law $\left(\frac{I_{primary}}{I_{secondary}} = \text{Constant}\right)$ of the ordinary alternating-current transformer seems therefore to extend also to the ratios of the various harmonics of the magnetizing current to one another in the case when the induced flux varies according to a simple harmonic law. The phase angles, α_1, α_3, α_5, etc., appear to vary only slightly within the same limits of flux density. Fig. 15 shows the analysis of the current i of Fig. 10B into its harmonics, and may be taken as typical of all the current waves from the tests carried out with the connections shown in Fig. 6. It will be seen that the peak in the magnetizing current is due to the approximate coincidence of the peaks of all the various harmonics.

In the above investigation the aim has been to obtain a flux in the Stalloy cores varying according to a simple harmonic law, this manner of variation being considered ideal. An examination of the table on page 255 giving the percentage deviation of Φ_m (actual) from Φ_m (apparent)

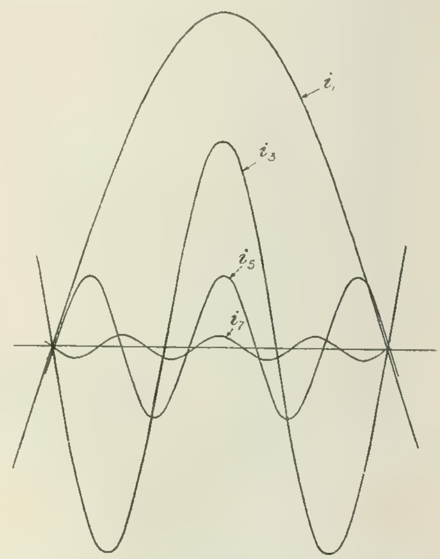


FIG. 15.—Analysis of Magnetizing Currents shown in Fig. 10B.

shows that the principal source of the deviation is the fifth-harmonic component of the flux. This harmonic would practically disappear if the fifth harmonic in the magnetizing current could be short-circuited in a manner similar to that of the third harmonic, I_3, as in Fig. 4 when the switch S is closed.

This method being impossible with 3-phase currents and three testers, the next best method is probably to insert condensers and variable inductances between the lines of the 3-phase circuit in Fig. 6 and gradually to vary the inductances until resonance with the fifth harmonic is obtained. Considerable success has already been attained by shunting the fifth harmonic in this manner, the switching in of the resonance circuit producing an appreciable lowering of the peaks in the wave of induced electromotive force, E_i, per phase. Experiments are being carried out with resonance circuits composed of 60 mfd. condensers in series with variable inductances having Stalloy cores, but owing to pressure of other work and to misfortunes with the oscillograph the author is not yet able to publish the results.

[illegible]

Discussion

[illegible] to eliminate the third harmonic, and the [illegible] for it in the value of the form factor of the [illegible]ve force in the search coil, by which the flux [illegible]ted, was possibly unsatisfactory, especially as [illegible]

[illegible] 15 cycles per second.

[illegible] taken all through for the coefficient instead of the indi- [illegible]

B	[illegible]	[illegible]	[illegible]	W_1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	25.5	[illegible]	1.755	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.42	[illegible]

[illegible] that the values for [illegible]

Professor Baily. give a smooth curve; but when the values of log B and log "Hysteresis" are plotted, it is found that the logs also give a smooth curve strongly convex to the horizontal axis, no part of it being straight, so that no formula of the form B^a can possibly be used. The logarithmic values are :—

B	Log B	Log "Hysteresis"
20,750	4·3170	0·3304
20,500	4·3118	0·3139
20,000	4·3010	0·2718
19,500	4·2900	0·2330
19,000	4·2788	0·2041
18,500	4·2672	0·1790
18,000	4·2553	0·1584
17,750	4·2492	0·1523

The hysteresis values in Table I are simply the total loss per cycle minus the eddy-current loss per cycle, and consequently are in joules for the whole volume of iron. This makes no difference in the determination of the index of B, and it is obvious by inspection that the relation of the two logarithms is not linear. Hence I must conclude either that there is some fundamental error in the author's method which systematically affects the values, or that at and above a flux density of 18,000 the hysteresis curve changes its character altogether and in the opposite direction to that which is to be expected. The latter conclusion requires more evidence before it can be accepted as probable.

Mr. Hird. Mr. W. B. HIRD: The connection between the mathematical formulæ of the paper and the physical facts which they represent is so familiar to the author that he has left out a number of steps of the explanation which to many of us appear by no means obvious. I will therefore venture to put the facts of the case in my own words in the hope that this may cause some members to take an interest in the paper who might otherwise be frightened away by the mathematical formulæ and the difficulty of interpreting them. Take any magnetic circuit—say a ring of plates—such as that used by the author and wound with a primary and a secondary circuit. If we can depend upon having a pure sine wave of primary current in the tester, then so long as the magnetic flux densities are small and it can be assumed that the flux is proportional to the current, we also get a sine curve for the flux and a sine curve for the secondary current. When, however, the flux densities are so high that the flux is no longer proportional to the current, this fundamental relation disappears, the flux at the top falls short of the values proportional to the current and is therefore not of sine-wave form, the secondary electromotive force is no longer a simple sine curve, and in order to deal with these curves mathematically we have to resolve them into various harmonics. Owing to the symmetry of the process which requires that the positive and negative parts of the wave should be similar, we can only have odd harmonics, and therefore we have to deal with a wave consisting of a fundamental, third, fifth, and seventh, etc., harmonics. In a very ingenious manner by using a combination of the properties of a star and a mesh connection in order to elimate the third harmonic and all its multiples the author is left with only the fundamental and the fifth, seventh, etc., harmonics. The third harmonic is of course the more important, and if it can be assumed that the fifth, seventh, etc., can be neglected, the flux remaining would be a true sine curve. The oscillograms show that there is a very pronounced fifth harmonic and that this cannot be neglected. The only way to get rid of these harmonics is that proposed by the author, viz. to insert suitable capacity and inductance so as to form a circuit having resonance for these harmonics. This method is of course much less satisfactory than the method used for eliminating the third harmonic, which is described in the paper, because it requires that the current should be supplied by the tester itself, that is to say, it cannot entirely eliminate the harmonic, but can only reduce its amplitude to a certain minimum. It is conceivable that methods of connection which would enable the fifth harmonic to be eliminated might be devised by using a larger number of phases, but the connections would evidently become extremely complicated, probably too much so for practical handling. This is the theory of the paper and it seems to me a very valuable contribution to the science of the magnetization of iron. From the practical point of view the author mentions some possible developments. Looking at the apparatus, not as a tester, but as a phase transformer, results have been obtained such as the obtaining of current with three times the frequency of the supply. In many cases this would be very useful, and further developments in this direction will be expected. It would appear at first sight, considering the large copper losses which must necessarily accompany any attempt to use iron at high magnetic densities, and also the hysteresis and eddy-current losses due to those high densities, that the efficiency of the apparatus must be low. The other practical point of view is the use of the apparatus purely as a tester in order to determine the actual losses in samples of iron at given maximum flux densities. For this purpose I think the method is much too elaborate. In the case of iron to be used for transformers, it might be worth while to attempt a much more elaborate and accurate determination of the losses than is at present usual in practice, but from the point of view of dynamo design I am certain that any methods of such an elaborate nature as that described in the paper would be really waste of time. Only in the vaguest way can we guess at the distribution of the flux in different parts of the magnetic circuit of the dynamo, and therefore only in a very vague way do we know the maximum flux densities in different parts. Under such conditions the approximation to the losses which is obtained from ordinary commercial methods of testing is as useful and serviceable as the most accurate results which can be got by elaborating the methods of test. Of course I do not wish these remarks to be taken as lessening in any way the value of work of this kind. We have found over and over again that the highest theoretical work, though it appeared to be of no immediate consequence to the practical man, has nevertheless proved of the greatest value directly or indirectly at some future time. I think there is no doubt that the value of this paper lies for the present in its more purely theoretical side—that is, in the new methods which it suggests of testing the magnetic properties of iron, and in the warning that it gives us that the actual flux densities in the iron may be much less than those apparently shown by the secondary electromotive force. The published results

[illegible]

Mr. W. W. Lackie: [illegible] did not give [illegible]

Mr. A. S. McWhirter: The advantages of using a 3-phase tester instead of a single-phase tester are very striking [illegible] possible with a single-phase tester; there is thus less likelihood of errors in the wattmeter readings. [illegible] are practically non-inductive. I think that the author's experiments should prove valuable for giving some idea of the error involved in assuming a sine wave when calculating B_m for a ring tester. At first sight there would not appear to be much improvement in e_i of Fig. 5A as compared with e_i of Fig. 2A.

Mr. A. L. Tackley: The results given in the latter portion of the paper show that within the limits of a maximum flux density of 17,500–20,000 lines per sq. cm. the shape of the magnetizing-current wave to produce a [illegible] mately constant. This suggested to me that this part of the subject might be approached mathematically, and with the author's permission I worked out a solution on these lines. The result is interesting since it shows exactly the conditions necessary in order that the shape of the current wave [illegible] also appears capable of being extended to certain other [illegible]

Dr. A. Russell [illegible]

[illegible] must be [illegible] the same way as shown in the paper, the values B_1, B_3, B_5 . . . for the harmonics of the flux density. Then, making the assumption that the amplitudes of these harmonics are approximately constant over t[illegible]

$$[illegible]$$

where t is the thickness of the strips in cm., and ρ equals [illegible] the wattmeter reading gives the sum of the hysteresis and [illegible] interested to notice that the author finds [illegible] to $B_m = 19{,}500$. In a paper recently read before the Physical Society of London, Mr. Stroude [*] finds that for Stalloy the values of the Steinmetz index are as follows:—

B_m	
[illegible]	[illegible]
[illegible]	[illegible]
[illegible] 4,000	[illegible]
4,000–12,000	[illegible]

[illegible] the high flux densities at which the author worked. It is [illegible]

[*] F. Stroude: An accurate exa[illegible]

Dr. Russell

worked. Mr. Nicholson's method of getting a flux of sine-wave form whilst most ingenious is rather too complicated for everyday use. Would it not be possible to devise a machine which would give an E.M.F. wave of such a shape that it would produce a magnetizing current of sine-wave form? An alternator with movable pole-pieces so that the shape of its wave could be varied, or one with excessive armature reaction, might be devised for this purpose. In the latter case the shape of the wave can be altered by adding inductance or resistance to either the armature or the field circuit until the desired shape is attained. The shape of the applied-potential-difference wave that will produce a current wave obeying the harmonic law in the magnetizing winding can readily be found when the hysteresis loop of the iron under test is known. In shape it is like a semicircle flattened on the top.

Mr. MacKellar.

Mr. D. J. MacKellar (*communicated*): I should like to ask the author whether the magnetic leakage at the high flux densities employed has been found to have any appreciable effect on the flux distribution in the tester cores, and whether it can be reasonably assumed that the flux density is uniform over the whole tester. His remark that "it is probable that a point may soon be reached at which with increasing electromotive force the maximum value of the flux density in the tester core actually begins to decrease" is very interesting, and no doubt many misleading results in tests where high flux densities (with alternating flux) are involved could be explained in this way. The methods of getting rid of the third and fifth harmonics are ingenious, and it would appear that the seventh and higher harmonics have a practically negligible effect for the range of flux densities employed. It would be interesting to know how the results of a test with the third and fifth harmonics eliminated would compare with the results of a test in which the harmonics were present but were corrected for as detailed on page 255.

Mr. Taylor.

Mr. A. M. Taylor (*communicated*): The subject of this paper is of great interest to transformer designers, though the information contained therein would have been of much greater value to me had it appeared a year ago, as it would probably have prevented mistakes in the design of a frequency changer—mistakes which proved expensive to rectify. The information is none the less welcome even now. The author's experiments have been made with a 40 k.v.a. alternator, with a core area of 7·5 sq. cm., and with pressures of the order of 20 volts; mine have been made with the supply from plant of a capacity of 25,000 k.v.a., with core areas of 300 sq. cm., and with pressures of 5,000 to 6,000 volts. My experiments were carried out on a 30/50 kw. frequency changer connected up as shown in Fig. 7 of the paper which I read before the Birmingham Local Section a few months ago,* and the essential difference between my experiments and those of Mr. Nicholson is that he has compelled the flux of his tester to follow a sine law, whereas my arrangement, in which the primary winding of the (unsaturated) working transformer is in series with the choking coil, rather tends to accentuate the natural tendency of the flux in the (saturated) core of the choking coil to depart from a sine law. I should be glad if Mr. Nicholson would explain how it is that the triple harmonic of electromotive force in the primary of the "working transformer" of my arrangement causes the terminal electromotive force in the choking coil to consist of a fundamental and a triple-harmonic wave in the negative (*i.e.* subtractive) sense to that fundamental instead of in a positive (*i.e.* additive) sense, as his curves appear to convey, and as I certainly expected. In regard to the losses in the iron, my experiments were carried out with choking coils weighing several hundredweights and immersed in oil tanks. I propose to calibrate the tanks for heat dissipation at ordinary flux densities and with a sine wave of flux; this will then enable me to determine by how much the energy losses at higher flux densities and with deformed waves of flux exceed those calculated from the tests of Stalloy as published in the maker's lists. The connections (see Fig. 4) used by the author are virtually those of the Spinelli frequency changer. Perhaps he can give us some figures to show at what rate the voltage E_{mesh} fell off as load was put on to the secondary coils D_1, D_2, D_3 connected as shown. The oscillograms in Fig. 5B would seem to show that the current in the mesh, when the latter was short-circuited, was hardly any larger than in Fig. 5A when it was presumably not short-circuited, which points to a considerable drop. Perhaps he will also say whether he has observed that the electromotive forces in the coils D_1, D_2, D_3, are simultaneous and all assist each other. I rather anticipated that in this arrangement there would be only two of these coils active at any moment.

* A. M. Taylor. Static transformers for the simultaneous changing of frequency pressure of alternating currents. *Journal I.E.E.*, vol. 52, p. 700, 1914.

Professor Robertson

Professor D. Robertson (*communicated*): The point dealt with in the paper is one of considerable practical importance in making magnetic tests by alternating currents, and the information given regarding the magnitudes of the different components of the magnetizing-current wave is of great interest. The author's method of eliminating the third harmonic in the induced electromotive force is very ingenious, but its application is somewhat limited by the amount of apparatus necessary to carry it out. For most purposes, one would probably prefer the simple method of using a single tester and then allowing for the distortion by determining the form-factor of the induced E.M.F. wave.* The importance of allowing for the air flux embraced by the search coil when the flux density in the iron is high is pointed out on page 255, but the figures given in the table for this correction do not seem to agree with the magnetization curve of Fig. 7. Thus, when the flux density in the iron is 20,000 C.G.S., that in the air would be about 480, or 2·4 per cent; but the air section is practically half that of the iron (0·336 to 0·664) and so the air flux will be 1·2 per cent instead of the 0·5 per cent given in the table. Possibly, however, these corrections have been calculated from the magnetization curves published by the makers, which give appreciably higher permeabilities than those in Fig. 7.

Dr. Smith

Dr. S. P. Smith (*communicated*): To my mind the most interesting fact in this paper from a scientific point of view is the action of saturated iron as a frequency converter. Though this phenomenon has been known for some time, I am not aware that a suitable and complete explanation has been given—at any rate the matter is not widely understood and deserves further attention. I remember that in a paper read by Dr. Coales before the Birmingham Local

* See, for instance, A. Campbell. Magnetic testing of iron with alternating current. *Journal I.E.E.*, vol. 43, p. 555, 1909.

[illegible]

Epstein apparatus, and it seems regrettable that such a [illegible] improvement, [illegible] the present paper, viz. how to obtain a sine-wave flux. It is not easy to appreciate the advantage of using such a flux, for provided the wave-form is determined by integrating the oscillogram of induced electromotive force, it is easy to ascertain the maximum value of the flux—upon which alone the hysteresis loss per cycle is [illegible] eddy-current loss is generally based on its definition as "the portion of the total loss which is proportional to the square of the frequency," but naturally this only holds good if the proportion between the harmonics and the [illegible]

[illegible] some extent this will be due to the fact that at the higher [illegible] abscissæ seemed to [illegible] are probably only approximately true. Until this correc- [illegible] is constant, since only two points fairly close together are [illegible] particular value of B_m. The sentence "Too great reliance must not be placed on the above deduction from [illegible]

Mr. Nicholson.

analysis given on page 253 and taking Professor Baily's figures, I get quite different values for eddy-current loss from those given by him, for example $B_m = 18{,}000$, total watts 37·8 and 24·3, and watts per cycle $W/f = 1·67$ and 1·62 respectively :—

$$W_1/f_1 = 1·67 = a + b f_1 \qquad \text{for } f_1 = 22·5 \text{ cycles per sec.}$$
$$W_2/f_2 = 1·62 = a + b f_2 \qquad \text{for } f_2 = 15 \text{ cycles per sec.}$$

Therefore $b = 0·00667$; $b f_1 = 0·150$ and $b f_2 = 0·100$; $a = 1·67 - 0·150 = 1·52$, as against the values of 0·250, 0·167, and 1·44 respectively deduced by Professor Baily for the eddy losses per cycle and the hysteresis loss per cycle. If Professor Baily will follow the above method of analysis he will get results for the hysteresis loss which agree very closely with those in the paper.

I agree with Mr. Hird that the paper may be rather difficult for many members to follow, but for various reasons it was deemed advisable to limit its bulk. The mathematical formulæ consist chiefly of expansions of electromotive forces, currents, and fluxes into series of sine waves of frequencies f, $3f$, $5f$, etc., and I trust that these will not repel any reader. The paper will of course be more directly available to those who have already carried out experiments with alternating-current testers. Mr. Hird rightly emphasizes the fact that the method proposed for the reduction of the fifth harmonic by short-circuiting it through a suitable capacity and inductance can only be partly successful. After a number of attempts to minimize this harmonic of the induced electromotive force in that manner I have now decided to abandon the resonance circuits. Designs have been got out for a 3-phase alternator to give currents of frequency $5f$, and to be connected in series with the main 3-phase alternator of fundamental frequency f. The magnetizing currents, i_1 and i_5, will then be supplied from external sources to the star-connected windings A of the testers, and the triple-harmonic current i_3 will be supplied as formerly to the mesh windings D. The efficiency of the frequency changer shown in Fig. 4 would be low, but owing to the fact that the primary current I_a varies with I_3 the efficiency need not be very low. With a terminal line pressure of 173 volts on the primary side (giving E_1 per phase = 100 volts), a secondary voltage of $3 \times 66·8 = 200$ volts may be obtained on open circuit, whilst with the small 3-phase generator at my command the mesh voltage had fallen 9 per cent when the current I_3 was one-third of its short-circuit value. Further information on this point will be obtained from Mr. A. M. Taylor's paper. I also agree with Mr. Hird that the method of testing is too elaborate for practical or everyday purposes; the method was devised for a scientific investigation of the subject, but I am hopeful that a simplification will allow of the maintaining of a simple-harmonic wave of flux even with single-phase testers.

Mr. Lackie mentions the presence of a third harmonic in a 3-phase star-connected static balancer. This is what may be expected whenever the star point of the choke coils is connected to the neutral wire. The star connection of the choke coils puts the three phases of the choke coils in parallel so far as the triple harmonics of the choke-coil magnetizing currents are concerned, and the neutral wire provides the closing link in the circuit for the triple-harmonic currents.

Mr. McWhirter calls attention to the fact that the power factor of the power measured by the wattmeters W_a, W_a, in Fig. 6 is approximately 0·5 instead of being approximately zero as in the ordinary tests with a single-phase tester. One of the wattmeters reads positive and the other reads negative, the total power being the algebraic sum of the readings of W_a and W_a. If then the wattmeters W_a form the two systems of a 2-phase wattmeter, such as the Drysdale instrument employed, great accuracy may be obtained in the measurement of the iron losses. For this reason alone the 3-phase connections probably represent a great advance in the accuracy with which the iron losses can be measured with an ordinary dynamometer wattmeter. Although e_i in Fig. 5A does not seem at first sight to be any improvement on e_i in Fig. 1A, the absence of an appreciable third harmonic in e_i of Fig. 5A means a very considerable smoothing out of the flux wave.

The mathematical deductions made by Mr. Tackley are most interesting, and throw considerable light on the subject of magnetization at high flux densities with alternating currents, and also provide an excellent check on the ratios of the harmonics of the magnetizing current obtained experimentally (see Fig. 14) when the flux density varied approximately according to a simple sine function of the time.

Dr. Russell challenges me with evading the mathematical difficulties of separating the eddy-current and hysteresis losses when the magnetic flux does not obey the sine law. I quite agree with him. I believe it to be worth one's while, in general, to elaborate an experiment if by so doing one can reduce the number of variables or reduce the magnitude of these variables and so obtain more uniform conditions and have fewer corrections to apply to the final experimental results. Dr. Russell gives an expression for the eddy-current losses in the general case; the shape of the induced E.M.F. wave alters, however, with the frequency—the lower the frequency the greater do the ratios of B_3/B_1, B_5/B_1, etc., become, and hence it is not possible to separate the eddy-current and the hysteresis losses by performing a number of experiments at constant B_m but at different frequencies.

I am very pleased to find that the preliminary results which I obtained for the Steinmetz index come approximately into line with those found at lower flux densities by Mr. Stroude. I am interested in Dr. Russell's suggestion of maintaining a sine wave of magnetizing current in the tester. This is the converse of the method described in the paper, but at very high flux densities the sine wave of current would produce a flux wave which approaches closely to a rectangular shape, a wave which therefore contains prominent higher harmonics and for which the quantity $(B_1^2 + 9\,B_3^2 + 25\,B_5^2 + \ldots)$ is large. I do not believe it would be so easy to obtain this sine wave of current as it would be to apply at the terminals of a single-phase tester such an E.M.F. wave that the induced electromotive force would be maintained a sine wave.

Mr. MacKellar calls attention to a possible un-uniform distribution of the flux in the tester cores. I think the leakage flux would not affect the distribution. The eddy currents might, however, do so if the core plates are thick, and especially if the flux does not vary according to a sine law.

Mr. Taylor had a great advantage over me in his

[illegible]

[illegible] until the nature of the load is known. [illegible] the current [illegible]

[illegible] beyond a certain critical value the [illegible] might be [illegible]

BIRMINGHAM LOCAL SECTION: CHAIRMAN'S ADDRESS

By A. H. RAILING, D.Eng., Member.

[illegible]

I have chosen as the subject of this address the position of electrical engineering in the world's social organization. I propose to show how and why in the chain of occupations and professions the advent of the electrical engineer [illegible] formations for the purpose of achieving further progress the duty to advance the age and the professions which have produced him, until he in turn has led to new and higher developments, to an increase in efficiency of matters [illegible] matter by man.

[illegible] spiritual, on the other, the mental worker himself often succumbs to routine. In such a state—as too often the [illegible] a unit that in its daily routine work has [illegible]

[illegible] with special functions for the various purposes [illegible]

In order to obtain the best overall efficiency, definite organisms have been created, specially devoted to and developed for specialized work. This overall efficiency in human society, however, will only be obtained when the specialized organism is aware of the bond connecting it to the common body, the reason for its specialization, the work that it has been created for, that part of the task which its predecessors have accomplished, and the tasks that are before it. Otherwise, instead of giving rise to increased efficiency, specialization is bound to lead to dissolution. Only the man who understands his work in this sense is worthy of the name "electrical engineer."

In order clearly to conceive our position, I propose to consider whether, as a body, we have a claim to be mentioned amongst the groups of workers whose names are identified in history with distinct and definite progress of humanity.

Man's original occupation was that of a hunter; he had to find food, and he had to defend himself. All classes since that day owe their existence to Nature's law of the survival of the fittest, *i.e.* the most efficient being. The most urgent immediate requirements of humanity were improvements in the methods of defence and of obtaining food in a more regular, secure, and easy way. The rearing of cattle and the tilling of the soil served this purpose.

Efficiency demanded that special knowledge, whether in regard to good or bad land, or to movement of sun and stars, or healing, should be centred in certain individuals, and handed on by them from one generation to another. Priest castes filled this gap, and from them separated in the course of time the physician, the teacher, the lawyer, and the philosopher.

As civilization progressed, humanity learned the use of materials. It learned the exchange of materials—the importance of the trader, who contributed to efficiency by removing the restriction in the use of certain commodities to certain localities and times.

The justification for all these classes of workers, therefore, was that they represented tools specialized for doing away with waste, either by producing more efficiently necessities of life, or by preventing undue waste of life, or by co-ordinating the actions of men so as to remove friction and waste, or by developing brain and morale, thus producing a more far-sighted, more efficient being, or finally by creating efficient communication between communities, thereby tending to equalize abundance and need.

All these vocations have already been in existence for thousands of years. Why has engineering, and especially electrical engineering, come so late, and what is its mission?

As humanity progressed, it dealt with men and matter as it found them, and it used the kinetic energy of men and animals, and perhaps of wind and water, as well as certain substances and some of their physical properties. Although attempts were made from time to time to probe deeper, practically nothing was known of the structure of matter, or of energy in its manifold variations. The problems of dynamics, if we leave out Aristotle, were dead until the time of Galilei and Newton; the problems of matter until Priestley and Berzelius. Engineering science meant, as in Galilei's law, going away from this earth, or, as in the atomic theory, going into the infinitesimal.

Electrical engineering started when humanity was prepared for an advance in this direction. In its narrower sense it means the application of the knowledge of what we call electricity. In its broader sense it is the knowledge of matter and its attribute "energy"—or, vice versa, energy which manifests itself in the form of matter—and their applications.

If we consider history as the progress of the knowledge of matter, the sequence is a logical one from physical properties to the properties of the molecule, from the problem of the molecule to that of the atom, and from the problems of atoms to those of the corpuscle, proceeding step by step to smaller and smaller units of matter.

If, on the other hand, we consider history as the progress of the knowledge of movements, we find exactly the same development from Galilei's and Keppler's law of the planets to the knowledge of the potential and kinetic energies of moving bodies, to heat and cohesion, to chemical energy, and from there to electricity and light, the energy of corpuscles, as the basis of all.

The knowledge of all these problems and the application of such knowledge went hand in hand, sometimes the application leading and the explanation following, sometimes theory first and application afterwards, and it is self-evident that the sequence depended partly on the greater pressure for practical application, the pressure to achieve something, to prevent something, or the greater need to understand certain facts, certain problems, and by understanding them to govern them.

I have tried here to show how and why engineering, and especially electrical engineering, came as the latest development proceeding from visible matter and the energy of visible matter, further and further into the region of the invisible and infinitesimal.

Having realized what led to our profession, I now come to the second point, which I set out to consider: In how far has electrical engineering already contributed to human development, by, shall I say, improving human progress and efficiency.

This problem has been dealt with in innumerable ways. I am not going to speak about the "thousands of miles of telephone wires, and the millions invested in electrical undertakings," which have become almost proverbial; nor shall I give statistics. I hope, however, to be able to show, shall I say from a philosophical point of view—which translated into modern language means a natural science point of view, or from the point of view of the laws of energy—that we have established our claim and have achieved greater efficiency in the universe.

What is the problem? Humanity, that is a number of human beings endowed with mental and physical energies (which may or may not be of the same nature), inhabits for a certain time a certain space. They have at their disposal a definite sum of matter in innumerable varieties and combinations, and a definite sum of energy, part of which is free energy in all its known forms, and perhaps in some that we do not know yet.

Electrical engineering is a power for civilization if it increases mankind's efficiency in dealing with these factors:—

(1) If it enables us to make better use of matter either by increasing the number of varieties in existence or by producing them more cheaply, or by making better use of their properties.

(1) [illegible]

(2) [illegible]

(3) [illegible]

(4) [illegible] ciency.

[illegible]

will be victorious, or the pure, shall I say corpuscular theory, which simply accepts substance with its energy as [illegible] personally accept the latter. For the present purpose, [illegible]

[illegible] tative knowledge resulted. Three different important discoveries had been made previously, more of a quantitative than a qualitative character.

(1) [illegible] stance (since the conception of mass may have to be changed in the light of Sir J. J. Thomson's [illegible]

(2) [illegible]

(3) The law of dissipation of free energy.

[illegible] it required a qualitative explanation, such as the one put forward so far in its clearest form by Sir J. J. Thomson, [illegible] In the light of these explanations, the world is the field of the electrical engineer.

[illegible]

[illegible] and in whatever form we require.

[illegible] to waste, *i.e.* being transformed into bound energy. Most [illegible] it to certain altitudes, transforms it into the kinetic energy of our rivers, and is stored and transformed into the chemical energy of coal, of oil, and of organic substances. [illegible] energy."

[illegible] apply them as light, heat, chemical energy, mechanical energy. Therefore it has either to transplant itself to [illegible]

(1) [illegible] transformed and electrical energy generated.

(2) Because electrons are the lightest carriers of electrical energy known, and therefore the easiest to transport; or, differently expressed, they carry a maximum amount of energy per volume of weight, and are therefore the most convenient form of energy [illegible]

(3) [illegible]

(4) [illegible] forms, allows us to store energy in a more convenient and more efficient way than would otherwise be possible.

If therefore, on account of these facts, it is possible to use the limited amount of free energy which is running to waste in our solar system, independent of its position (by transmitting it) and time (by storing it) we have one of the most valuable results and achievements for mankind.

The four advantages shown lead us to the most important fields of electrical engineering, in its narrower sense, to electrical generation, electrical transmission, electrical re-transformation, or application to motive power, heat, lighting, and chemical processes, and finally to electrical storage.

(1) Generation.

We have shown that the solar energy is available for use either in the form of kinetic energy in our rivers or in the form of chemical energy in plants and other organic substances, the one running to waste all the time (*i.e.* being transformed into bound energy), the other one stored. Where kinetic energy is available, as in water and wind, the transformation into electric energy is ideal. The efficiency of the process of transformation is fairly high, and the capital outlay, especially where high velocity can be obtained, comparatively low (with the exception of tidal works where large masses have to be employed, since the potential energy per volume is small). Efficiencies of say 90 per cent can be commercially obtained.

Where chemical energy has to be transformed, the efficiency of transformation is still low, and it is to be hoped that in time either some more efficient mechanism of transformation may be found, or that it may be possible to transform the energy of radiation direct into electrical energy, without the intermediate steps of heat and mechanical energy, each one of which is of course a source of loss. The direct transformation of chemical into electrical energy through primary cells, and of heat into electrical energy by thermo batteries, whilst useful for specialized purposes, is, on account of the relatively small energies which come into play, of secondary importance.

(2) Transmission.

The transmission of electrical energy can be accomplished with a higher efficiency than that of any other form of energy (except electromagnetic radiation). We can construct transmission lines 50 or 100 miles long having 85 to 90 per cent efficiency, and we could transmit electrical energy over still greater distances if free energy became so scarce that a higher capital outlay for the transmission line would be advisable. The only alternative, transmission by radiation, whilst practicable and carried out for small amounts of energy, is yet impracticable for large quantities, for the same reason that light cannot be transformed conveniently into electrical energy, *i.e.* because an efficient mechanism of transformation has not yet been discovered. An excellent potential field for research is here open.

(3) Application.

The re-transformation of electrical energy into other forms of energy is to-day so well known that energy can be obtained in all the forms in which we can apply it.

Light.—This is produced relatively with efficiency, since we can conveniently obtain high temperatures at which the ratio of light rays to heat rays is great, *i.e.* the transformation losses are low. We produce it cheaply because of the low losses in transmission and transformation; furthermore, because the method of starting and stopping is simple, can be carried out at a minimum cost, and can be effected by remote control. We produce light without the bad influence on human organisms exercised by all other methods which rely on the oxidization process. It is clear that these facts make us work more efficiently, independent of movement of the sun, *i.e.* of day and night; they also obviate to a certain extent the differences between the seasons in countries of high latitude, increase our efficiency for work indoors and underground, and prolong in general the time of work and of life under suitable sanitary conditions.

Heat.—As in the case of light, heat is produced without creating fumes, without a long period for starting and stopping, with the possibility of remote control and of easy, simple, and efficient regulation. For domestic purposes of heating and cooking we are only at the beginning of the development. For industrial purposes, it need only be stated that electrical energy, beside the advantages already mentioned, allows us to produce higher temperatures than by any other known means, and that it allows us to concentrate heat on limited areas better than in any other known manner. Electrode furnaces and induction furnaces were developed to apply heat in this way. This knowledge has given us a new metal in aluminium, and has enabled us to produce high-class steel electrically, to melt quartz, to manufacture calcium carbide, carborundum, and graphite, and to fuse and weld metal. It has presented us with all the advantages connected with the application of these materials in their new or cheapened form, and has therefore resulted in their more general use.

Chemical energy.—By passing the current into solutions containing copper, silver, and gold, these metals are refined. We are able to reduce them from low-grade ores, by electrolytic methods, such as gold by the cyanide process. The great increases in the industrial consumption of such metals, for instance of copper (42,000 tons in 1870 to 700,000 tons in 1907, with a price reduction from £105 in 1870 to £65 per ton in 1907), have only been rendered possible because electro-chemistry allowed us to work up lower-grade deposits of copper by economic methods. Zinc and lead are produced in a similar way.

Gold, silver, and copper can be deposited by means of the electric current: the origin of the plating industry. We produce oxygen and hydrogen for oxidizing or reducing processes in connection with numerous industrial applications, like the bleaching of cotton and paper, and for sterilization purposes. By electrolytic processes we produce caustic soda. We separate the nitrogen out of the air and make nitrates to fertilize the soil. We produce chemical energy for the growth of those plants which we can assimilate in our human organism, so as to replace the free energy which we spend—a long row of energy transformations this last series—from the corpuscle energy which in the electric arc combines nitrogen and oxygen from the air, until it becomes mental or muscular energy in our body.

Only when we look closely into transformations of energy such as that just mentioned, does it become clear to us that such a series of immensely complicated transformations can only be performed by extremely fine transmission apparatus, with energies highly concentrated in small masses, and that the dynamic energy of larger

[illegible]

[illegible] the individual and average comfort of living in producing centres.

[illegible] has the advantage over other forms of energy for use on [illegible]

[illegible] cost of necessities and luxuries, and consequently increased [illegible] centres, were thus extended to a wider and wider area, [illegible] different climatic conditions, in countries of old civilization, [illegible]

[illegible] make better use of the material and the energies available in the universe.

[illegible] thus increasing the radius [illegible]

[illegible] the others.

Without [illegible] the knowledge of their ap[illegible] practically the whole of [illegible] of modern society, an [illegible] the world, of life, and of [illegible] ethics, and of reading and writing, all originally known to [illegible] evident that they mattered more than anything else for life and progress.

[illegible] the individual, I must add one other reason why electrical engineering and knowledge of it increases the individual mental and physical power and efficiency.

[illegible] and chemical processes have to serve. There are not new laws for living matter and old ones for dead [illegible] domain.'

It is clear that if the theory of corpuscles helps us to understand what we call dead organisms, it will help us to understand the living ones in all their manifestations.

It may be further assumed that if we have learnt better [illegible] not yet definitely proved, but it is equally [illegible]

knowledge of electrical matters and especially the theory of ether, or, as we know it now, of the corpuscle, has enabled us partly to prove existing laws in organic matter, and partly to form pictures, working hypotheses for chains of facts, which otherwise could hardly be understood.

Amongst a few, the mechanism by means of which our senses receive and transmit an external stimulus to the central organ of the brain, and how they respond to an internal stimulus, has been explained. It has been found that the tissues of vegetable and animal matter respond to any external stimulus of heat, radiation, or other electrical or mechanical energy in a definite way, which, if not constituted, is at any rate accompanied by a movement of corpuscles, a movement that can be galvanometrically measured. The influence of strength of stimulus as producing a definite strength of sensation, positive or negative, its change with the dying of the tissue, its alteration when conductivity is altered by anæsthetics, and its strength when produced by internal energy of the human body as against an external one, have been ascertained, and in this way we have definitely established some laws, showing that in the human body the receiving and transmitting mechanisms are of partly electrical nature. There are scientists who go so far as to say that they consider all processes of living matter are produced by corpuscles, such as growth, contraction of muscles, genesis, etc., or, as Arrhenius says, "It is the ions which work, they produce contraction in heart and muscle." Biologists and psychologists have actually explained memory, inheritance, and telepathy, by means of the vibration of electrical corpuscles, and if these explanations are far from conclusive, it must be confessed that they give a better picture of the facts than any other yet in existence. If through this better understanding, only some of the factors that influence these phenomena can be definitely ascertained in regard to quantity or quality, and be thereby made amenable to our influence, an immense vista of new tasks would be in front of electrical engineering.

Electrical engineering in mastering matter is trying to probe into the mechanism of living organism and into problems which concern the human body and mind. In every result which they have achieved, and in every further one that they may unravel, these endeavours mean an increase in the efficiency of the individual.

I have thus already started on the last proof that I have to give for the mission of electrical engineering, namely, its influence on improving the collective efficiency of mankind. It is clear that the last-mentioned problems are of as much importance for human society and its efficiency as for the individual.

I have shown that electrical engineering has acted as a great, perhaps the greatest, democratizing agent. It has taught us to make full use of the materials and energies available, and thus, on the one hand by cheap production, and on the other by cheap transportation, has made commodities and tools, which were the properties of the few, the tools and properties of the masses of mankind.

Its second influence consisted in replacing to an ever-increasing extent manual labour by other available energies, thus conferring a further boon on mankind by allowing us to spend our energy more and more in a form which we are allowed to call a higher one—mental energy. The very great progress in science during the last century is largely due to this fact. Science and knowledge, through this emancipation of mental energy, have become, from the labour of the few, the labour of many.

In conclusion, I wish to refer to a third factor contributing to the efficiency of the human race. This efficiency, as has been already pointed out, greatly depends on the universal spreading of knowledge or experience that has been gained by individuals either in theory or application. Such knowledge originally adhered to the individual until language enabled him to communicate with his fellow-men, until the written, and later on the printed sign allowed him to hand it over to a greater and greater number. To-day, the knowledge of one individual can be within an hour the knowledge of mankind in all distant parts of the globe. The transmission of messages by electric currents in a cable or by radiation in wireless telegraphy has removed the time factor and the factor of distance in the spreading of knowledge throughout the universe.

Though the picture is not complete, I think I have shown that electrical engineering has led to a better understanding, a more extended and a more efficient use of nearly all existing matter and energy. It has led to a better understanding of animal and human organisms and problems. It has bridged space and time and minimized their influence where they become resistance factors against energies mental and physical, it has increased the efficiency of individuals and of society, and it has therefore established its claim to be one of the most valuable factors in the progress of mankind.

For the electrical engineer, however small and however unimportant his specialized work may often appear to him to be, this knowledge should be a profound source of satisfaction and happiness and a spur to increased activity. Happiness, if we look at it purely from the energy point of view, should of necessity be such a spur. It acts as a tonic, that is, either in the form of better conductivity between the brain centres or in our receiving apparatus of nerves, or in our electromechanical transformer of muscles, or in general as a better efficiency of all the energies which we accumulate in our system and which we spend mentally and physically.

Happiness has been defined as the product of human energy spent and progress (positive or negative) achieved by an individual or a class.

The knowledge of what as a class we have accomplished should therefore act as a stimulant to further work. Whilst we have as a definite achievement a picture which describes the world—matter in all its variations—much remains to be cleared up, from the structure of the atom, the mechanism of the corpuscle, and the problem of continuity which Sir Oliver Lodge has put before us, to the knowledge of the mechanism of the transforming apparatus for the various energies and the actual construction of such apparatus. Much also remains to be done from the design of machinery for the increased concentration of energy in all its forms to the design of machinery for the thousand-and-one forms, applications for which we have to specialize so as to embrace an ever-increasing knowledge, and to study an ever-increasing variety of applications of that all-pervading substance which we call electricity, ether, corpuscle, and which forms and means the universe.

In this sense the profession of electrical engineering, the history which led up to it, the tasks which it has accomplished, and the problems which it still has to conquer, should be understood.

THE CURRENT TRANSFORMER.

By A. G. L. McNaughton, M.Sc., Associate Member.

([illegible])

Summary.

(1) Introduction.
(2) [illegible]
(3) [illegible]
(4) A [illegible] method of [illegible] and phase angle.
(5) [illegible]

The [illegible] current transformer consists of [illegible] a primary through which the line current passes, and a secondary [illegible] and closed through the current coil of an ammeter, wattmeter, watt-hour meter, or of a relay.

The current transformer is used in alternating-current measurements to insulate the instruments from the line and to reduce the current to a value convenient for measurement.

In order to determine the primary current from the reading of the ammeter in the secondary, it is necessary that the ratio (primary current/secondary current) be known; and it is desirable that this ratio remain nearly constant, independent of the current throughout the range of measurement.

When the current transformer is used in connection with a wattmeter for the determination of power, or with a watt-hour meter for the measurement of energy, in addition to the above ratio the phase of the secondary current with reference to the primary current must be known. This angle should preferably be small.

The vector value of the voltage generated in the secondary is given by

$$\bar{E}_s = \bar{I}_s \{ (r + r_s) + j\, 2\pi f (L + L_s) \}$$

where f = frequency,

r = resistance and L = self-inductance of load,

r_s = resistance and L_s = leakage of transformer secondary,

$\bar{I}_s$ = vector value, and I_s the R.M.S. value, of the current in the secondary winding of the transformer.

The maximum value of the flux required to generate this voltage is

$$\Phi = \frac{E_s}{\sqrt{2}\,\pi f n_s}$$

where n_s is the number of turns on the secondary. The flux vector is in quadrature (leading) with the electromotive force vector E_s.

Substituting for E_s

$$\Phi = \frac{I_s}{\sqrt{2}\,\pi f n_s} \sqrt{(r + r_s)^2 + (2\pi f (L + L_s))^2}$$

The phase of the current $\bar{I}_s$ lags behind that of the flux by the angle

$$\alpha = \tan^{-1} \frac{[illegible]}{[illegible]}$$

The current in the primary consists of the following components:—

(1) The current, $\bar{I}_1 = -\frac{n_s}{n} \bar{I}_s$.

The phase difference between $\bar{I}_s$ and $\bar{I}_1$ is π and hence the phase of $\bar{I}_1$ leads that of the flux by the angle

$$\tan^{-1} \frac{[illegible]}{[illegible]}$$

Fig. 1.—Vector Diagram of Current Transformer.

[illegible]

(2) The magnetizing current, $\bar{I}_m$, which is in phase with the flux, its relation to the latter being shown in Fig. 2.

(3) The current, $\bar{I}_h$, supplying the hysteresis loss. This is given by $[illegible]$; or, substituting $E_s = \sqrt{2}\,\pi f \Phi n_s$,

$$I_h = \frac{K}{\sqrt{2}\,\pi n_s} \Phi^{[illegible]}$$

This current is in quadrature (leading) with the flux. K depends on the quality and volume of the iron used, and at the low flux density used in the current transformer cannot be treated as a constant.

(4) The current, $\bar{I}_e$, supplying the eddy-current loss given by $[illegible]$. Substituting for E_s, $I_e = \frac{K_e f}{\sqrt{2}\,\pi n_s} \Phi$ and is in quadrature (leading) with the flux.

K_e depends on the quality and volume of the iron used and also on the square of the thickness of the laminations. The eddy-current loss in the copper can usually be neglected.

The value of the total primary current is

$$\bar{I} = \bar{I}_1 + \bar{I}_m + \bar{I}_h + \bar{I}_e$$

[illegible]

Resolving into components respectively in phase and in quadrature with the flux,

$$I = \left(I_1 \frac{X}{Z} + I_m\right) + j\left(I_1 \frac{R}{Z} + I_h + I_e\right)$$

where $X = 2\pi f(L + L_2)$,
$R = r + r_2$,
and $Z = \sqrt{R^2 + X^2}$.

The core-loss current is given by $I_c = I_h + I_e$.

The exciting current is given by $I_o = \sqrt{I_c^2 + I_m^2}$.

Substituting in the above equation, the total primary current

$$\begin{aligned} I &= \left(I_1 \frac{X}{Z} + I_m\right) + j\left(I_1 \frac{R}{Z} + I_c\right) \\ &= \frac{n_2}{n_1}\left[\left(I_2 \frac{X}{Z} + I_{m2}\right) + j\left(I_2 \frac{R}{Z} + I_{c2}\right)\right] \end{aligned}$$

where I_{m2} and I_{c2} are the magnetizing and core-loss currents referred to the secondary of the transformer.

The numerical value of I is

$$\begin{aligned} I &= \frac{n_2}{n_1}\sqrt{\left(I_2 \frac{X}{Z} + I_{m2}\right)^2 + \left(I_2 \frac{R}{Z} + I_{c2}\right)^2} \\ &= \frac{n_2}{n_1}\sqrt{I_2^2 \frac{X^2 + R^2}{Z^2} + 2\, I_2 \frac{(X\, I_{m2} + R\, I_{c2})}{Z} + I_{m2}^2 + I_{c2}^2} \\ &= \frac{n_2}{n_1}\sqrt{I_2^2 + \frac{2\, I_2 (X\, I_{m2} + R\, I_{c2})}{Z} + I_{o2}^2} \end{aligned}$$

where I_{o2} is the exciting current referred to the secondary of the transformer.

The ratio is

$$\frac{I}{I_2} = \frac{n_2}{n_1}\sqrt{1 + 2\frac{(I_{m2} X + I_{c2} R)}{I_2 Z} + \frac{(I_{o2})^2}{(I_2)^2}}.$$

The angle of lead of the primary current with reference to the flux is

$$\tan^{-1}\frac{I_2 R/Z + I_{c2}}{I_2 X/Z + I_{m2}}.$$

Now the angle of lead of I_1 (the primary component balancing the secondary load current) with reference to the flux is $\tan^{-1} R/X$. Hence the phase of I_1 leads that of I by the angle

$$\begin{aligned} &\tan^{-1}\frac{R}{X} - \tan^{-1}\left(\frac{I_2 R/Z + I_{c2}}{I_2 X/Z + I_{m2}}\right) \\ &= \tan^{-1}\left[\frac{\dfrac{R}{X} - \dfrac{I_2 R/Z + I_{c2}}{I_2 X/Z + I_{m2}}}{1 + \dfrac{R}{X}\,\dfrac{I_2 R/Z + I_{c2}}{I_2 X/Z + I_{m2}}}\right] \\ &= \tan^{-1}\left(\frac{I_2 R X/Z + I_{m2} R - I_2 R X/Z - I_{c2} X}{I_2 X^2/Z + I_{m2} X + I_2 R^2/Z + I_{c2} R}\right) \\ &= \tan^{-1}\left(\frac{I_{m2} R - I_{c2} X}{I_2 Z + I_{m2} X + I_{c2} R}\right) \end{aligned}$$

Determination of Constants.

The relation of I_{m2}, I_{c2}, and I_{o2} to the generated voltage is determined by an open-circuit test. The secondary winding is connected in series with a low-range ammeter and a wattmeter current-coil to the line. The potential coils of the wattmeter and of a voltmeter are connected to the transformer terminals. Readings of amperes, volts, and watts are taken, and the "active" and "reactive" currents are calculated.

The reactive current is I_{m2}.

The active current, corrected for the current in the meter pressure-coils, is I_{c2}.

The exciting current, I_{o2}, is $\sqrt{I_{m2}^2 + I_{c2}^2}$.

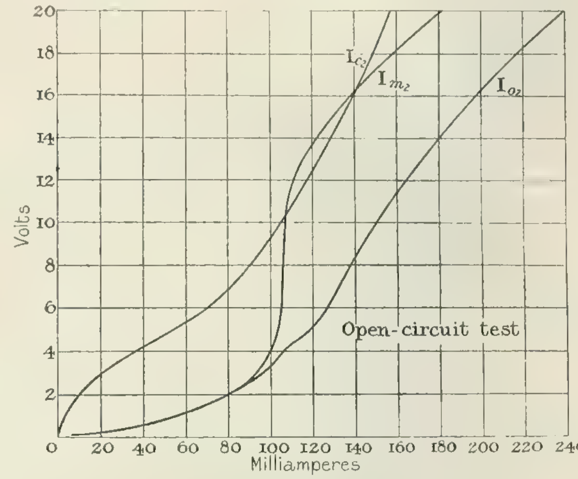


Fig. 2.

The equivalent impedance, reactance, and resistance of the primary and secondary windings in series, taken with the primary short-circuited, may be calculated from the readings of the voltmeter, ammeter, and wattmeter.

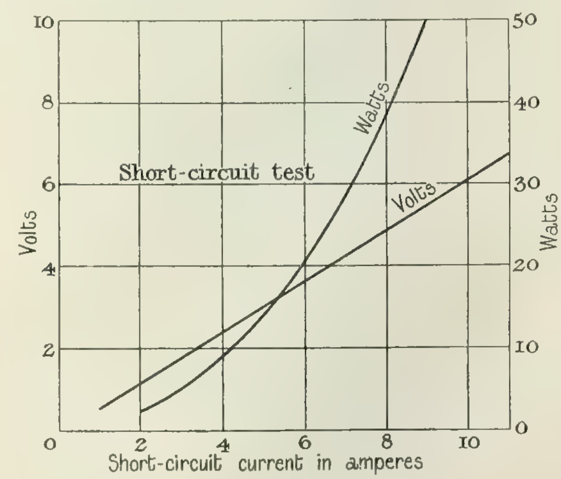


Fig. 3.

The secondary leakage reactance is approximately one-half of the total reactance. The secondary resistance may be estimated similarly, but is preferably measured with continuous current.

The resistance and reactance of the meters and leads are obtained from the readings of the voltmeter, wattmeter, and ammeter, when the secondary circuit is closed through them and the primary winding is excited.

The numerical values of the ratio and phase angle may be obtained by substitution in the respective expressions.

Figs. 2 and 3 give the results of the open-circuit and

[illegible] Fig. 4 shows the relation

Fig. 4.

of the ratio and the phase angle to the secondary current and Fig. 5 the effect on these quantities of increasing the

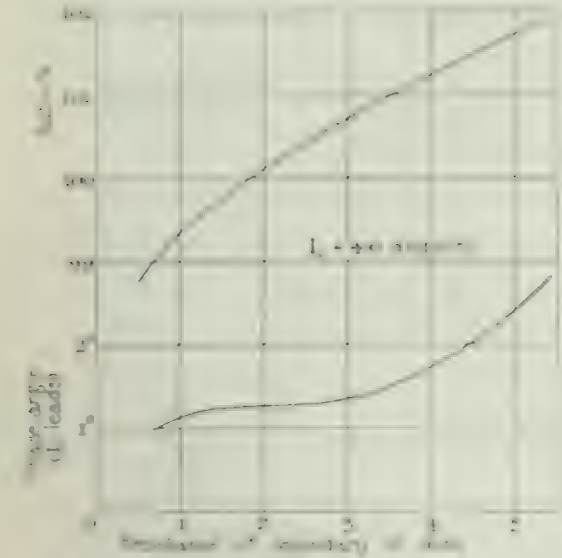


Fig. 5.

resistance of the secondary circuit. (Actual observations give results coinciding closely with the calculated curves.)

The expressions for the ratio and the phase angle are of theoretical interest as showing the general effect of resistance and reactance load and that of magnetizing current, hysteresis current and eddy currents on the ratio and the phase angle of the transformer; but for practical purposes, since it is difficult to measure I_o accurately, it is better to determine the ratio and the phase angle corresponding to the particular conditions of a measurement, that is, with the same instruments, loads, frequency, wave-form and temperature.

The ratio and the phase angle under actual conditions may be conveniently measured, with an accuracy sufficient for industrial purposes, by means of a standard, very [illegible] and two wattmeters connected as shown in Fig. 6.

Fig. 6.

The current and the voltage are brought to [illegible], the phase adjuster is adjusted to bring the reading of W_1 to zero and the others are read. The ratio then equals reading of A_1/reading of A_2, and the phase angle [illegible] W, A, E, W_1, A_1 and E being the readings of the respective instruments.

Fig. 7 shows the effect, as measured by this method, of frequency on the ratio and on the phase angle.

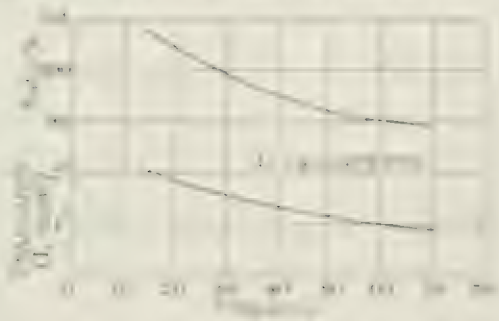


Fig. 7.

The iron used in modern instrument transformers is of such excellent quality, and the instruments are made so that I_1 and I_2 are nearly equal, so that the phase angle usually represents a lead of the secondary over the primary current.

Previous magnetic treatment, such as [illegible] suddenly removed, [illegible], has a marked effect on the magnetizing and core loss currents and hence also on the ratio and the phase angle. Before use, therefore, the iron of the current transformer should be brought to a neutral condition by opening the secondary circuit and putting full load on the primary, the primary current then being continuously reduced to zero.

PROCEEDINGS OF THE INSTITUTION.

ORDINARY MEETING OF 10 DECEMBER, 1914.

Proceedings of the 572nd Ordinary Meeting of The Institution of Electrical Engineers held on Thursday, 10 December, 1914—Sir John Snell, President, in the chair.

The minutes of the Ordinary Meeting held on 26 November, 1914, were taken as read, and confirmed.

The list of candidates for election and transfer approved by the Council for ballot was taken as read, and was ordered to be suspended in the Hall.

The President: I was unable to refer at our last meeting to the news which we heard just before that meeting of the loss to our Navy of H.M.S. *Bulwark*. The Commander of that vessel, Captain G. L. Sclater, had been a Member of this Institution since 1903, and took a very great interest in electrical matters. Although he did not die fighting, he gave his life quite as much in the service of King and country as if he had done so. I therefore ask you to pass a vote of condolence to his widow and relatives, by all standing in silence.

The resolution was duly passed.

A paper by Mr. E. B. Wedmore, Member, entitled "Automatic Protective Switchgear for Alternating-current Systems" (see page 157), was read and discussed, and the meeting adjourned at 9.45 p.m.

ORDINARY MEETING OF 14 JANUARY, 1915.

Proceedings of the 573rd Ordinary Meeting of The Institution of Electrical Engineers, held on Thursday, 14 January, 1915—Mr. J. S. Highfield, Vice-President, in the chair.

The minutes of the Ordinary Meeting held on 10 December, 1914, were taken as read, and confirmed.

The Chairman: Owing to the illness of the President, Sir John Snell,—not serious illness, I am glad to say—I have been asked to take the chair to-night.

Messrs. A. G. Collis and W. E. Butcher were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the result of the ballot was declared as follows:—

Elections.

Members.

de Souza, Edgard Egydio.
Vyvyan, Richard Norman.

Associate Members.

Blair, Frank.
Bridger, Thomas William.
Climie, Henry Richmond.
Fuller, Algernon Clement, Capt., R.E.
Laurie, Donald Saunders.
Parker, William Leonard.

Associate.

Harris, Douglas Gordon.

Graduates.

Atkins, Sidney James.
Briggs, John Cockbain.
Dawson, William John M.
Edgar, George Thomas.
Fairfield, Thomas James.
Grover, Charles.

Graduates—continued.

Houghton, Samuel Birchall.
Kemp, Henry Donald.
Lewis, Edward.
Little, Douglas.
McGuinness, Charles Joseph.
Manley, George Thomas.
Pettifor, Walter Hayward.
Prescott, Charles William W.
Rose, Percy Thomas.
Winter, Harry Norman.

Students.

Baxter, William Morley.
Brazel, Claude Hamilton.
Chowna, Cawasji Pallonji, B.A.
Cole, Norman Henry.
Dancy, Wilfrid.
Dowerah, Bidyananda.
Doyle, Henry.
Farmer, Claude Douglas.
Fiske, Alfred Reginald.

Students—continued.

Ford, William Arthur.
Freedman, Paul.
Garland, Cecil Clifford.
Grainger, Otto W.
John, William James.
Jones, John Williams.
Jones, Leslie John.
Kerr, Philip Cameron.
Lye, Donovan Henry C.
Messer, William G.
Murray, Leslie E. Ruthven.
Needham, Joseph Frank W.
Parkinson, Arthur Muir.
Pearce, James George.
Rau, M. R. Raja, B.A.
Rendle, Gerald Alfred.
Schroeder, Francis Herbert.
Sheldrick, John Engledow.
Stevens, George Carson.
Tirunarayanan, M. B., B.A.
Vaidya, Mahadev Vaman P., B.Sc.

TRANSFERS.

Associate Member to Member.
Anderson, John Adam.
[illegible], Augustus [illegible].
[illegible], Henry George.

Associate to Member.
[illegible], Max [illegible].

Associate to Associate Member.
[illegible], Archibald.

Graduate to Associate Member.
[illegible], Christopher J.

Student to Associate Member.
[illegible], [illegible] Frank.
[illegible], Albert.
[illegible], Frank [illegible].
[illegible], [illegible].
[illegible], George [illegible].
Hartley, Gerard.
[illegible], Alfred, B.Sc.
[illegible], Reginald [illegible].
[illegible], George [illegible].
[illegible], Andrew [illegible].
[illegible], [illegible].
[illegible], Albert George.
[illegible], Joseph [illegible].

Student to Graduate.
[illegible], John [illegible].
[illegible], Robert.
[illegible], [illegible].
[illegible], George [illegible].
[illegible].
Riley, Tom.
[illegible], [illegible].
[illegible].
[illegible], [illegible].
Wood, [illegible].

Mr. W. M. Mordey: It is my purpose (and I think you will agree I [illegible] in adding one—that a few words should be said here publicly when a pioneer in our branch of engineering passes away. It is my duty tonight to refer to the loss which the Institution has sustained in the death of Augustus Stroh. Mr. Stroh was probably not personally known to many of you; he was a very old man when he died, and he has not been seen at our meetings for a long time. His work has been that of a great man and of a great pioneer. He was a German by birth, having been born at Frankfort in [illegible]. He died in London on the 2nd November last. He was therefore [illegible] years old. He came to England on a holiday at the time of the 1851 Exhibition, and was so impressed by our free institutions that he settled here, becoming a naturalized Briton in [illegible]. He was connected with this Institution almost from the beginning, having become a Member in [illegible]. He was on the Council altogether for [illegible] years between [illegible] and [illegible], and was Honorary Auditor from [illegible] to [illegible]. He was also Honorary Auditor of the Benevolent Fund for nine years from [illegible]. To show that his was a real and practical interest, I may mention that he bequeathed [illegible] to the Benevolent Fund of the Institution and [illegible] to our Building Fund. Those whose memory or knowledge goes far enough back will be aware of Mr. Stroh's close connection with the early development of telegraphy. Soon after he came to England he became associated, as mechanician and assistant, with Sir Charles Wheatstone, with whom he collaborated in the carrying out to success of many practical inventions. The well-known A B C telegraph instrument, which is [illegible], is generally known by the name of Wheatstone, but it is recognized that the carrying out of that beautiful piece of electro-mechanism was largely due to Augustus Stroh, who also assisted in the development of another beautiful and very successful piece of telegraphic apparatus, which is still largely used by the Post Office here and in other countries. I refer to the Wheatstone automatic high-speed telegraph instrument. For this work he was awarded a Gold Medal by the International Jury of the Paris Exhibition of [illegible]. His work was not confined to electrical and mechanical inventions. He devised instruments for use in almost all branches of physics. He was a scientific mechanician of the very highest position. When he was a young man in Germany it is related that he was known amongst his comrades in the clock industry in which he began life as "the prince of mechanicians," and anyone who knew him and knew his work will agree that that was a well-deserved title. All his work was distinguished by the very greatest nicety, accuracy, skill, and ingenuity. He made, I suppose, hundreds of inventions. The factory which he established for the manufacture of his own inventions and of the Wheatstone telegraph apparatus was in [illegible] taken over by the Post Office. Stroh then retired from business, but he devoted himself until almost the end to experiments in mechanics and in electricity. I am afraid I am one of the few here tonight who remember the paper he read before the Institution in [illegible] on "Attraction and Repulsion due to Sonorous Vibrations, and a Comparison of the Phenomena with those of Magnetism."* It was illustrated by very many delicate experiments carried out by the author with unfailing success—a striking demonstration of ingenuity and manipulative skill. The well-illustrated account in the *Journal* may be referred to with interest and profit. He also occasionally took part in our discussions, principally on telephonic and microphonic matters. He was always a close friend of that other mechanical and electrical genius, David Hughes, our Past-President, the two men being very much alike in many of their qualities and characteristics. They were close friends up to the time of the death of Hughes. In musical matters Stroh also took a great interest. He was associated with

* Journal I.E.E., vol. [illegible], p. [illegible], [illegible].

Wheatstone in the invention of what is called the English concertina—an instrument that I believe musical people consider is really a musical instrument. He also in comparatively recent years invented what is known as the Stroh violin, in which there is no body, the vibrations being transmitted to a diaphragm provided with a trumpet. As to his personal qualities, of which modesty and kindliness were pre-eminent, I can only say that nobody could know him without liking him very much. I do not think I can close these remarks better than by reading to you a few words from a notice of Mr. Stroh in *Engineering* of a month ago,* written by Mr. Conrad Cooke, who knew him intimately: "So has passed away a man who, although his name was practically unknown to the general public, was truly a great man; for his inventions, several of which are of the highest importance, may be counted by hundreds. His house remains a monument to the fertility of his inventive genius, for it contains hundreds of the most delicate instruments devised by himself, and made with his own hands, all exhibiting a perfection of workmanship. It was the extraordinary modesty of Mr. Stroh—amounting to almost self-effacement—that prevented him from having the highest honours conferred upon him. He was always not only ready, but eager, to place his unrivalled skill as a mechanician at the disposal of all his friends, and he will be missed for a very long time by a coterie of admirers, for he won the esteem and affection of all who had the privilege to know him."

A paper by Messrs. S. P. Smith, D.Sc., Associate Member, and R. S. H. Boulding, Student, entitled "The Shape of the Pressure Wave in Electrical Machinery" (see page 205), was read and discussed, and the meeting adjourned at 9.50 p.m.

* *Engineering*, vol. 98, p. 599, 1914.

INSTITUTION ANNOUNCEMENTS.

COMMISSIONS IN ROYAL GARRISON ARTILLERY.

The President is informed that the vacancies for commissions in the Royal Garrison Artillery for which, at the invitation of the War Office, he recently nominated a number of young engineers have all been filled for the present.

ENGINEER UNITS—ROYAL NAVAL DIVISION.

The Adjutant has written to the Secretary of the Institution as follows :—

With further reference to the matter of commisions I have to inform you that in view of the fact that this Unit will be leaving for active service at no very distant date, it has been decided that no N.C.O. or man is to be allowed to leave the Unit for the purpose of taking up a commission in another branch of H.M. Forces except by the direct permission of the G.O.C. i/c. This consent will only be granted in very special cases.

I think it is only fair that any members of your Institution who are considering the question of joining this Unit should be made aware of the above.

ACCESSIONS TO THE REFERENCE LIBRARY.

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THE SIXTH KELVIN LECTURE

LORD KELVIN'S WORK ON GYROSTATICS.

By Professor A. Gray, LL.D., F.R.S., Member.

[illegible]

I.—Gyrostatic Experiments in the Glasgow Class-room.

[illegible] gyrostats [illegible] appearance on the lecture-table, and [illegible] These gyrostatic questions, like many of our exercises in natural philosophy, were often of a numerical character. It is always a good thing to get down to numbers, and it is a [illegible] healthful mental discipline to be forced to "get the [illegible] right." Our equipment for the solution of these [illegible] the apparatus, that he rather frequently forgot to give us the full dynamical explanation of the curious evolutions which we beheld. I well remember how puzzled I was by the proof which we had placed before us, that the rate of [illegible] round of the axis of a gyroscope in azimuth was [illegible] the moment of the applied couple, [illegible] that in the general case there are two [illegible]

[illegible]

The lectures that we had were undoubtedly most interesting and suggestive, though they were not perhaps always directed to the more prosaic topics which formed [illegible] of wood, wh[illegible] imagined to be generated by the revolution of an ellipse [illegible]

Fig. 1.

[illegible] This is of course [illegible]

[illegible]

inertia is a maximum), the solid shows that when spin is applied the equilibrium is unstable. The ellipsoid at once sets itself on one end, and then rotates in stable equilibrium with the long axis nearly vertical. This is a very remarkable result. The centre of gravity has been raised, and the equilibrium is now stable. The spin has altered the conditions of equilibrium completely.

Of course it was pointed out to us that all these phenomena are well shown by the ordinary spinning-top, spun by the unwinding from it of a string when the top has been skilfully thrown from the hand. Schoolboys are not encouraged now (indeed they are *dis*couraged by prefects and other important personages) to play with tops and marbles, and thus many phenomena of spin and collision which some of us used to observe are missed. The swaying round of the axis of a top when rising just after spin to the "sleeping" position, and the similar conical motion of the axis when the top is about to fall, give examples of precessional motion, of, in fact, the astronomical phenomenon called precession of the equinoxes.

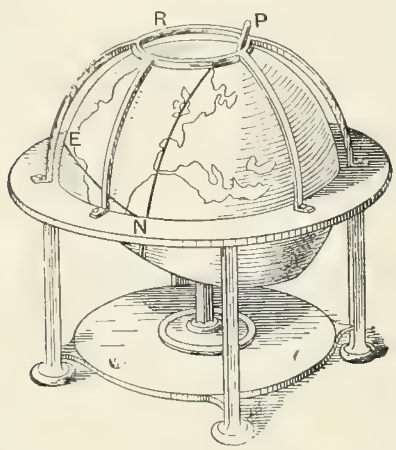


FIG. 2.

Precession was illustrated by the interesting old model of a terrestrial globe which I have here (Fig. 2). You see that the globe is weighted so that a pin projecting from the North Pole rolls round a ring, that is a narrow cone fixed in the earth rolls in the inside of a cone fixed in space. These cones have their vertices at the earth's centre, the axis of the fixed cone is perpendicular to the ecliptic and its semi-angle is 23° 27′, that is, an angle equal to the obliquity of the ecliptic. On this ring, which represents the ecliptic, you have the intersections with it of the earth's equator—that is, the equinoxes—and so, as the earth turns, the two intersections move along the ecliptic, the equinoxes precess. The earth, in fact, is a top on which we happen to live, the spin is one turn in 24 sidereal hours, and the conical motion is completed in a period of 26,000 years (Fig. 3). One of our problems was to calculate the diameter of this pin for the earth, or, as it was sometimes put, to find the diameter of the North or South Pole! If I remember aright the diameter is about 21 inches.

These were our first gyrostatic experiments and illustrations. I must not omit to mention that the spinning of the ellipsoid was attempted also with each of two eggs, and that with one the experiment always succeeded, and with the other always failed. The reason of this failure and success was interesting; and although some students laughed at the experiment, it nevertheless arrested the attention of all. The contents of one egg were a viscid liquid, the contents of the other had been subjected to a process of coagulation by prolonged exposure to an elevated temperature. In other words, one egg, the one that would not spin on end, was raw, the other had been boiled hard. I now repeat this experiment, which is the scientific solution of the famous problem of Christopher Columbus, to make an egg stand on end.

It is very easy to show, on principles which I hope to explain later, why the solid prolate ellipsoid, the piece of wood, or the hard-boiled egg, sets itself on end when it is spun about one of the shortest diameters; it is not at all easy to show why the raw egg does not.

There is another point in this connection to which I wish to direct attention. I see in the papers from day to day, especially the country papers, notices of abnormally large eggs laid by fowls, and I have myself observed that some eggs are more prolate than others, but so far I have not come across an oblate one! An egg in the form of an oblate ellip-

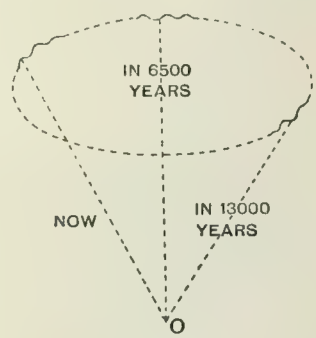


FIG. 3.

soid of revolution, that is, of the external shape produced by the revolution of an ellipse about its shorter axis, might be spun about that axis, and would continue so to spin; a prolate one would not continue to spin about its axis of figure. As we cannot obtain an oblate egg, we make up one of sheet metal filled with water, and try to spin it. I have one here that I shall show you presently, and we shall see that it can be spun without difficulty. The possibility of spinning an oblate ellipsoidal mass of liquid was discovered mathematically by Colin MacLaurin, Professor of Mathematics at Edinburgh in the first half of the eighteenth century. He showed that, provided the angular speed was kept under a certain limit depending on the density of the fluid, there were two revolution ellipsoids of different eccentricities, which were figures of equilibrium for a mass of liquid spinning about the axis of figure, with its surface free. With one or other of the eccentricities proper for the speed, the case may be supposed removed without affecting the equilibrium. Of course it is understood that there is no terrestrial gravity to produce disturbance; the spinning ellipsoid of liquid, without enclosing case, could not be realized except in the laboratory at the centre of the earth that Lord Kelvin used to long for, and perhaps for various reasons not even there.

All this is connected with a subject to which Lord Kelvin

[illegible]

2. Dynamical Theory of Rotation of Plane of Polarized Light.

[illegible] at the plane of polarized light transmitted through a [illegible] to be explained by a helical structure of the medium; [illegible] rotation of that plane, by passage of the light through [illegible] by the wave of light.

Think (as I heard him once say) of a transparent elastic medium full of little helical hollows of the order of 1/40000 inch in dimensions, having all their axes turned the same way, so that to an observer looking along them the helices are all right-handed or all left-handed, or at least are preponderatingly in one direction or the other. [illegible] in the direction of the axes of the helices, waves of torsional displacement at different speeds according as the torsion is right-handed or left-handed. Hence a wave of circularly polarized light would, he suggested, travel at different speeds in that direction, according as the displacement involved was right-handed or left-handed, for the elastic reaction would be greater in one case than in [illegible] may be regarded as consisting, would travel together in the same direction at different speeds, and a difference of phase would grow up, which would account exactly for the turning of the plane of polarization.

The turning of the plane of polarized light, which takes [illegible]

[illegible] pagated in [illegible] existing motion, [illegible] $F_2 = F_1 + 2f$. [illegible] gain on the other.

Fig. 4.

The illustration proposed was a double pendulum. A cord (see Fig. 4) is attached at the two ends of a horizontal rod A B, and to the middle point of this cord is fastened a simple pendulum, of length l as indicated. The distance of the bob from the rod is l', that is l + O C. The rod is [illegible] a massive particle.

[illegible] which is $2\pi\sqrt{l/g}$ for vibrations in the plane of the paper [illegible] motions.

[illegible]

[illegible]

where x, y are the co-ordinates of the bob and $\dot{x}$, $\dot{y}$ their time rates of change, and $\ddot{x}$, $\ddot{y}$ are the accelerations corresponding.

The second terms on the left-hand sides of these equations, $2\omega\dot{x}$, $-2\omega\dot{y}$, are in form what were called afterwards by Lord Kelvin gyrostatic terms, and the conditions for the existence of real periods of oscillatory motion in the general case, depending, as the reality of these periods does, on the value of ω, gives us an idea of what he termed in that connection "gyrostatic domination."

In an Appendix to this lecture will be found a synopsis of the solution of this interesting case of motion with some modifications of notation and mode of presentment. The reader may refer also to the original paper.* It is reprinted as Appendix F of Lord Kelvin's "Baltimore Lectures."

The main results may be expressed as follows :—

(1) If a long straight rod, which is unequally elastic in two rectangular directions, or is of unequal diameters in these directions if of uniform elastic quality (a rod of elliptic section, for example), be rotated rapidly about its axis, and vibrations be maintained in a fixed transverse direction at one end, waves of rectilinear vibration, the direction of which slowly turns round as the wave advances, will be propagated along the rod.

(2) Let the transverse elasticity of the medium, which to fix the ideas may be taken, as has already been suggested, as a long straight rod, along which waves of transverse displacement are propagated in the direction of its length, vary with the direction of the transverse, so that it has maximum and minimum values in axial planes at right angles to one another. If this rod be slightly and uniformly twisted about its axis these planes become helicoidal or screw surfaces. Think now of a line in space parallel to the axis of the rod. This line will intersect either of these surfaces at points whose successive distances apart are all equal to the step s of the screw. If the rod be turned about its axis as a whole each point of intersection will move along the line at a speed v which depends on the rate of turning.

Let a rectilinear vibration be kept applied at any cross-section, say one end, and let the rod be rotated about its axis in the proper direction, and at such a rate that the speed v just specified is equal to the velocity of propagation of the wave produced by the applied vibration. The result will be that a series of waves of rectilinear vibration will run along the rod, without any turning of the plane of vibration in space. In order that the rotation may be rapid it is necessary that the wave-length, a say, should be many times the step s of the screw.

According to our notation the period of vibration is $2\pi/\mu$, and therefore the velocity of propagation of the wave is $a\mu/2\pi$. But if s be the step of the screw, and ω denote as before the angular speed of rotation, the value of v is $\omega s/2\pi$. Hence we must have $\omega s = a\mu$ or $\omega = a\mu s$.

The effects of the twist and rotation thus exactly balance one another. The latter (see Appendix) gives a rotation of amount $\frac{1}{4}\pi\lambda^4/\omega^3\mu$ in a wave-length, or a complete turn in $8\mu\omega^3/\lambda^4$ wave-lengths. Hence the effect of a single turn of twist in a length s is equivalent to that of rotation in $8\mu\omega^3/\lambda^4$ wave-lengths.

The dynamical illustration is thus applicable to all the cases of turning of the plane of polarization of light. There is one point of difference, however, which renders a rotational medium more truly representative of the magneto-optic turning, and is decisive as between a rotational and a structural explanation of the different phenomena. A beam of plane polarized light which has traversed a piece of heavy glass in a magnetic field will, if it be reflected and sent back through the medium, have the turning of the plane doubled by the backward passage, while backward passage through quartz or a sugar solution annuls the turning produced by the forward passage. These facts point, as Lord Kelvin repeatedly urged in his teaching, to a rotational explanation of the magneto-optic effect and to a structural explanation for the other.

I shall return to this subject in discussing Lord Kelvin's explanation of Faraday's phenomenon of magneto-optic rotation by gyrostatic action as set forth in later papers; but I may remark here that in his paper * on "Magnetism and Molecular Rotation" he definitely discarded his gyrostatic hypothesis, at least as an explanation of Zeeman's discovery of the effect of a magnetic field applied to a source of light in modifying the spectral lines. Of course the idea of convection currents due to moving electrons and the action of a magnetic field on such currents, and of the light as due to electromagnetic action in an insulating medium, through which the electric disturbance is propagated, has completely altered the views of physicists regarding the medium and its necessary constitution. There is, however, still a correspondence, to a considerable extent exact, between the dynamics of such systems as that here discussed, and also gyrostatic systems, on the one hand, and the optical or electrical action on the other. [This I have dealt with in § (11 of the Appendix to this lecture.]

3. Precessional Motion of a Liquid.

About 20 years later gyrostatic problems attracted Lord Kelvin's attention in a very special way. From 1875 onward for several years he was much occupied with many things, for instance he transacted much business connected with submarine cable instruments, eclipsing lights for lighthouses, and compasses and sounding machines. I was one of his assistants, and remember how busy we all were. For the two years from 1875 to 1877 there are set down in the list of his papers four on the subject of gyrostatic action, but of these only two were ever printed, the first and the last. The former was entitled "Vibrations and Waves in a Stretched Uniform Chain of Symmetrical Gyrostats," † the latter "On the Precessional Motion of a Liquid." ‡ I shall first give some account of the latter paper, because it contained descriptions and illustrations of gyrostats and gyrostatic action, and shall then return to the former.

The circumstances in which this paper was written were interesting. In 1875 Lord Kelvin (then Sir William Thomson) visited America as one of the judges of Group 25 (Scientific Instruments) of the Centennial Exhibition at Philadelphia. There he saw many things that were new and of very great interest, among them Bell's newly invented telephone, and met most of the

* *Loc. cit.* above.

* *Transactions of the Royal Society of Edinburgh*, vol. 20, 1899; *Math. and Phys. Papers*, vol. 5, p. 354.

† *Proceedings of the London Mathematical Society*, vol. 6, p. 190, 1875; *Math. and Phys. Papers*, vol. 4, p. 533.

‡ *British Association Report*, 1876, Transactions of Sections, p. 1

[illegible] in the interior liquid by its rotation. [illegible]

[illegible] however, that [illegible]

At the Glasgow Meeting of the British Association in 1876 Lord Kelvin was President of Section A, and began [illegible]

[illegible]

which begins the complaint of the poet that no matter what hero he wished to sing, his lyre refused to respond to [illegible]

[illegible]

[illegible]

[illegible]

provided with bearings at the ends. Round the case, as nearly as may be in the central plane of the flywheel, is a projecting rim, the edge of which is not quite circular, but rather polygonal with curved sides, and the points of meeting of the sides rounded off. The rim serves to support the gyrostat, as it stands on this glass plate, in some of its evolutions.

The bearings are cups in which the rounded points of hardened steel of the axle run. This is not a good arrangement if the gyrostat is to be subjected to shocks, or to be roughly handled in any way. Oiling also is required, after every second spin at least. In our new gyrostats we use ball bearings designed to resist considerable shocks and stresses without derangement. With these, in some experiments, we have gone up to speeds of about 25,000 revs. per minute, and have found the flywheel to be still rotating rapidly after the lapse of 45 minutes. Also the wheel may be run for several hours with only one oiling.

It will be convenient to show here some of the experiments usually performed in the Ordinary Class of Natural Philosophy in Lord Kelvin's time. The multiplicity of subjects put down to be treated in the dynamical part of the course precluded, as I have hinted, any detailed explanations of these experiments. They were carried out in fact with the avowed and excellent purpose of exciting curiosity in the minds of the students, and a desire to find out why gyrostats behave in a manner at first sight so anomalous. Interest was certainly aroused in a few, but I fear that the majority despaired of penetrating such mysteries, and sought external help for the mastering of the more hackneyed topics of the degree examinations.

The process of spinning excited more interest than any other part of the experiment, for the ordinary elementary student cares more for a little bit of sensation than about the scientific result to be proved. A long cord was laid out on the floor, then the free end passed one and a half, or two and a half, times round the axle of the gyrostat, which was held by the operator, with its axis vertical, in a suitable socket on a table fixed to the floor. An attendant holding the free end ran away with it, slowly at first then faster and faster, down a long passage and through a large adjoining room, while friction was applied to the cord as it entered the gyrostat case.

For the runner was substituted later a large wheel with grooved rim on which the cord was wound as it was drawn through the gyrostat. I estimate that speeds of about 100 turns per second or less, may have been obtained in this way. Now, of course, one spins by an electric motor, as I shall presently describe.

I will make one or two of the experiments with the original gyrostats, but it will save time if I repeat the others with some of the new and improved gyrostats invented by Dr. J. G. Gray, whom I am fortunate in having to assist me on the present occasion.

First then taking this gyrostat, the oldest I believe of the collection, I spin it with this motor arrangement on the table. The shaft of the flywheel is made to bear on the rough edge of a disk carried by the overhanging shaft of the motor. The motor is run slowly, and the operator makes the surfaces bear lightly on one another at first, then he increases the speed and bears more heavily until the motor and the shaft have attained their full speed.

I now hold the spinning gyrostat with its axis of spin horizontal, and slip a noose of cord over one end of the part of the case round the axis, and leave the arrangement to itself (Fig. 6 shows this experiment, but the gyrostat

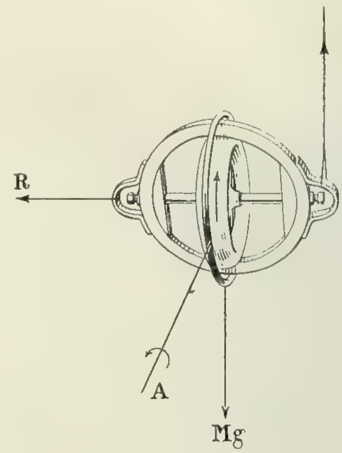


FIG. 6.

used was that indicated in Fig. 7). You see that the axis of spin remains horizontal, and at the same time turns round apparently in a horizontal plane. In reality the axis alternately descends slightly below and rises slightly above the horizontal; but a true horizontal motion can be got by properly starting the gyrostat in the azimuthal motion, and then leaving it to itself. I call the horizontal or azimuthal motion of the axis a "precessional motion" of the gyrostat.

The same thing can be shown by suspending the gyrostat by a cord attached to the rim, and hanging a

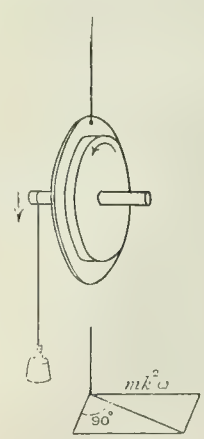


FIG. 7.

weight by a cord to the part of the case surrounding the axle. The diagram shows the arrangement and the directions of turning (Fig. 7).

This behaviour of the gyrostat is often considered paradoxical, and must I suppose be regarded as difficult to explain in a popular manner. At any rate the popular explanations are as a rule extremely unsatisfactory. Yet in this particular case of horizontality of the axis the matter

[illegible]

[illegible] Mounting.

Look at the thing now in this way (see Fig. [illegible]). The axis [illegible] with angular speed Ω say. Now, and this is the point [illegible] rate of production of angular momentum about the axis A of the couple. For when an axis with which is associated a directed quantity, L say, is turning towards a fixed direction at right angles to it with angular speed Ω, there is a time-rate of production of the quantity associated with the latter direction measured by the product LΩ.*

Now the flywheel is revolving with angular speed ω, so that if its moment of inertia is [illegible], it has angular [illegible]

* [illegible]

[illegible] would cause the axis to begin to descend. In each case [illegible]

[illegible] surrounds the case, the gyrostat is set with its axis not [illegible] motion in which the axis moves in a cone round the vertical.

Here it is important to remark that there are two [illegible] The former to the first approximation does not depend on applied forces, the other does. Lord Kelvin called the former "adynamic," the other "precessional." But in strictness both involve the forces, and they appear [illegible] steady motion, which is characterized by slow precession, given very nearly, but not quite exactly, by the same [illegible]. The other motion of the axis in the same cone is one of much greater precessional angular speed, which is given by a more complicated formula (see Appendix). I do not think I ever heard Lord Kelvin refer to this latter motion in his lectures, but it can be [illegible] I have seen of gyrostatic steady motion as a rule ignore this second possible motion.

[illegible]

seem to be generally known, as the rule is generally stated absolutely.

It is important to notice that if the centre of gravity of the gyrostat is above the point of support, supposed on the line of the axis, the two precessional motions are in the same direction; if on the other hand the centre of gravity be below the point of support, the precessional motions are in opposite directions. The faster motion changes sign in passing through an infinite value, when the axis is horizontal.

By the effect of hurrying or retarding the precession was explained the rising and falling of a top spinning on a rounded peg in contact with a rough floor along which the top can move. At first the spin is fast and the slipping is such as to produce a hurrying friction couple which causes the erection of the top. After the spin has fallen off the slipping is the other way and a couple which produces the reverse effect results, and the top falls.

Another of Lord Kelvin's experiments was that with a gyrostat supported on a universal gimbal joint as shown in

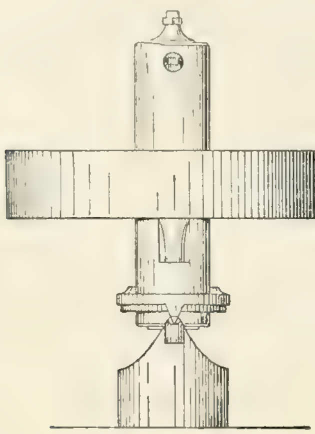


Fig. 9.

the diagram (Fig. 9). This drawing shows only one gimbal axis clearly: the other axis is at right angles to this and is hidden by the upper ring to which the knife-edges are seen attached. Here is the gyrostat formerly always employed in the experiment, which, however, I can carry out more readily with the new apparatus. You see that the gyrostat thus mounted forms an inverted pendulum, which has two freedoms of motion, and when the wheel is without spin is unstable in both. With spin the gyrostat is stable in both freedoms.

This is an example of a doubly unstable arrangement rendered completely stable by spin. In Thomson and Tait's "Natural Philosophy" the interesting theorem is proved (at least it is implied in the discussion in § 345, *et seq.*) that in a gyrostatic system an even number, but not an odd number, of freedoms can be stabilized by rotation of flywheels. Of this we have here a particular case.

Here is another arrangement of double instability which was always shown (Fig. 10). I believe the idea was due to the late Professor Blackburn. A trapeze is attached at its ends to two vertical chains by two rings attached to two swivels, so that the trapeze can turn about its own longitudinal axis. The trapeze is made of two slips of wood between which the rim of the gyrostat can be slipped and secured by a pin. One of the chains you see has inserted in it a large ring, so placed that by unhooking one of the chains, passing it through the ring, and then rehooking it, and turning the trapeze end for end, we have it suspended by crossed chains. Such a bifilar suspension is of course unstable, as the trapeze tends to turn round towards

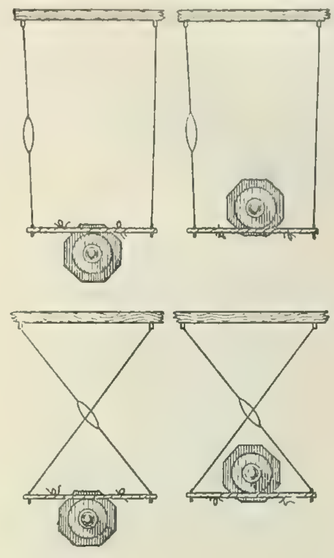


Fig. 10.

assuming the arrangement of two parallel or uncrossed chains, in which of course the centre of gravity is lower than in the other case, and which so far as the bifilar is concerned is the arrangement of stable equilibrium without spin.

The gyrostat when without spin and hanging below the trapeze, with the chains uncrossed, has two freedoms for both of which it is stable: (1) The system can swing as a

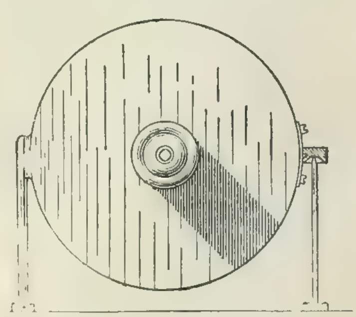
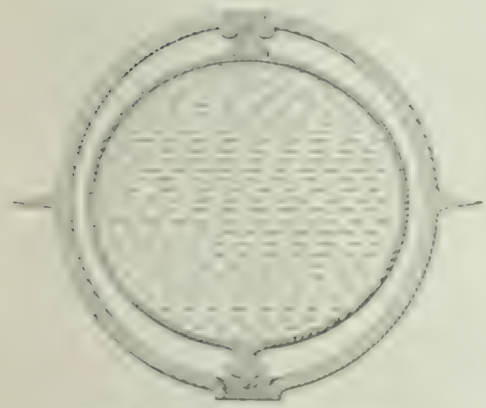


Fig. 11.

pendulum about the swivels at the end of the trapeze; (2) the trapeze can turn in azimuth about a vertical axis through its middle point, in vibrations in which the chains are carried in opposite directions out of the vertical. These two modes of motion are thus both stable modes without spin of the flywheel.

Now when the chains are crossed, and the trapeze is turned so that the gyrostat is above it, both freedoms are

[illegible]



[illegible]—Liquid Gyrostat [illegible]

[illegible] of steel, pointed at both ends, if placed with one end in the cup and with the other end resting on this steel plate on the table, forms another leg or stilt. We could hardly [illegible]

[illegible]

[illegible]

This spheroid has an oblateness of about 5 per cent, that is the difference in length of the polar and equatorial [illegible] motion of the water, into which the rotational motion [illegible] globe is impossible.

[illegible]

be sufficiently prolate. The axial diameter, in fact, must either be shorter than the equatorial diameter, or be more than three times as long. As Sir George Greenhill points out, a modern elongated projectile if filled with a liquid would not rotate steadily about its axis of figure, and therefore would not have a definite trajectory as a rifle bullet has; it would turn broadside on to the direction of motion.

5. Gyrostatic Theory of Elasticity.

One other experiment I shall make with the veteran gyrostat, which has been spun again. You see that the rim carries two trunnions in line with the centre of the wheel (Fig. 14).* These are placed on bearings attached to this square wooden frame; and now you see that as I hold the tray in my hands in a horizontal position, the gyrostat rests with its axis vertical or nearly so. The direction in which the wheel is spinning is shown by the arrow on the upper side. I now carry the tray round in azimuth in the direction of spin: nothing happens; the gyrostat spins on placidly.

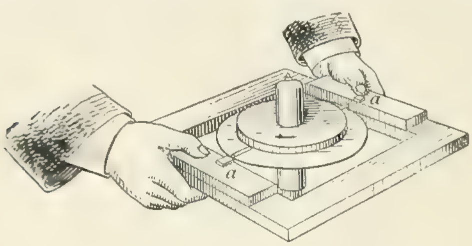


Fig. 14.

If, however, I carry the tray slowly round the other way, the gyrostat immediately turns upside down on the trunnions; and now, as I go on carrying the tray round in the same direction as before, the gyrostat is quiescent as at first; but the spin, by the inversion of the gyrostat, has been brought into the same direction as the azimuthal motion.

The gyrostat behaves as if it possessed volition—a very decided will of its own. It cannot bear to be carried round in the direction opposed to the rotation, and, as it cannot help the carrying round, it accommodates itself to circumstances by inverting itself so that the two turning motions are made to agree in direction. Again I reverse the azimuthal motion, and the gyrostat inverts itself so that the wheel turns in the same direction in space as at first.

The inversion brings into play a wrench on the hands of the experimenter. A varying couple, lasting during the time of the inversion, is required to reverse the angular momentum of the wheel in space, and this is applied to the gyrostat by the frame at the trunnions, and to the frame, because that is kept steady, by the hands of the operator. The total change of angular momentum is $2N$, where N is the angular momentum of the flywheel, and this is the time-integral of the couple.

It will be noticed that in this experiment, in which the gyrostat displays this curious one-sided stability and instability, it is affected by a precession impressed upon it from without. The system was not left to itself, I carried it round. The gyrostat had little or no gravitational stability—the centre of gravity was nearly on a level with the trunnions; but even if it were gravitationally unstable, sufficiently rapid azimuthal motion would keep it upright if that motion agreed with the spin, while the least motion the other way round would cause it to capsize.

It is important to notice that if the gyrostat be placed on the trunnions, so that the axis of the wheel is in the plane of the frame, azimuthal turning in one direction causes one end of the axis to rise, or turning in the other direction causes the other end to rise. As I shall show presently, this means a reaction couple on the frame which must be balanced by a couple applied by the experimenter.

Better than anything else I know, this experiment affords an example of the two forms of solution of a certain differential equation, which, when the gyrostat is without sensible gravitational stability, and θ is small, I may write

$$A\frac{d^2\theta}{dt^2} + \omega N\theta = 0,$$

where N is the angular momentum of the wheel, and ω the angular speed with which the tray was carried round. When the turnings were in the same direction, ω and N had the same sign, but when the turnings were in opposite directions the product ωN had a negative value. When the product is positive we have a solution giving oscillations about the vertical, in the period $2\pi\sqrt{A/\omega N}$: the equilibrium is stable. When, however, ω is reversed the product must be given the opposite sign, and we get a solution in real exponentials, giving continued falling-away from the upright position until the opposite position, which is stable, is attained. N has now also been reversed in space, and the product ωN in the differential equation is again positive.

As I have already stated, the time integral of the turning moment about the vertical, required by the gyrostat from the frame constraining it to move round in azimuth, is $2N$, that is $2Cn$, where C is the moment of inertia of the flywheel about its axis. There is thus at each instant of the turning in azimuth, before the inversion has been completed, a couple required from the frame, and this couple is greater the greater the angular speed n of spin.

The couple arises thus. Let the gyrostat axis have been displaced from the vertical through an angle θ about the trunnion axis. In consequence of the azimuthal motion, at rate ω say, the outer extremity of the axis of angular momentum is being moved parallel to the instantaneous position of the line of trunnions, and thus there is rate of production R of angular momentum about that line; but there being no applied couple about the trunnions, the gyrostat must begin to turn about the trunnions to neutralize R. This turning tends to erect or to capsize the gyrostat according as the spin and azimuthal motions agree or are opposed in direction. In its turn, however, this involves production of angular momentum about the vertical for which a couple must be applied by the frame, and of course to the frame by the operator. This couple is greater the greater Cn, and therefore if the operator cannot apply so great a couple an azimuthal turning at rate ω cannot take place. With sufficiently great angular momentum the resistance to azimuthal turning could be made for any stated values of θ and ω greater than any specified amount.

The magnitude of this couple which measures the resistance to turning at a given rate is greatest when the angle

* *Proceedings of the Cambridge Philosophical Society*, 1880; "Encyclopædia Britannica," article, "Hydromechanics."

[illegible]

[illegible]

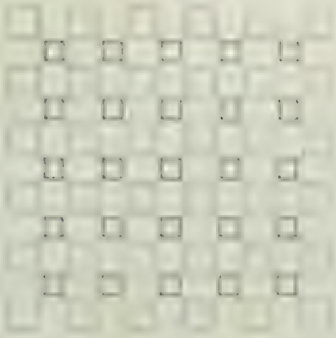


FIG. 15.

[illegible] tions. If the web is strained slightly by a small change of each flexible square into a rhombus, or into a not square [illegible] the areas are to the first order of small quantities [illegible].

Now imagine that a gyrostat is mounted in each of the rigid squares, so that the axis of the trunnions and the axis of rotation are in the plane of the square as shown in Fig. 16. [illegible]

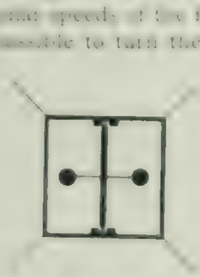


FIG. 16.

at any given small angular speed. Thus any strain involving turning of the small squares is resisted, and we have azimuthal rigidity conferred on the web by the gyrostats. There is, however, no resistance to non-rotational displacement of the squares as wholes.

[illegible] In each cube he supposed mounted three gyrostats with their trunnions at right angles to the three pairs of sides. [illegible]

[illegible]

[illegible]

[illegible]

FIG. 17.

realizing this arrangement which is shown in Fig. 17, but on consideration I found that though it would act as a spring, it would not, except under certain conditions, not easily realizable even approximately, possess the [illegible] hook. The gyrostatic arrangement is very difficult to [illegible] with our motor instruments. You see what the arrangement is. [illegible] jointing the bars freely together at their extremities [illegible] diagonal of the frame is vertical, and another vertical [illegible] shown, with its axis along the bar, and they have equal rotations in the directions shown by the circular arrows. Under the couples tending to change the directions of the [illegible]

[illegible]

gyrostats and bars, the system precesses round the two swivels, and so preserves a constant configuration. If now a weight is hung on the hook at the lower end, the frame is elongated a little, and a new precessional motion gives again a constant configuration of the frame, different of course from the former one. Two gyrostats, the upper or lower pair, would serve quite well to give the effect.

Lord Kelvin suggested that if the frame were surrounded by a case, leaving only the swivel-pins at top and bottom protruding, it would be impossible, apart from special knowledge of the construction of the interior, to discern the difference between the system and an enclosed spiral or coach spring, surrounded by a case and fitted with hooks for suspension and attachment of weights. I find, on working out the steady motion of the system under gravity, that unless the masses of the gyrostats are very small (while their angular momenta are exceedingly great), so that the change of kinetic energy due to the change in precessional motion may be put down entirely, or nearly so, to the work done by gravity on the weight carried by the hook, in its descent from one configuration of steady motion to another, the distance through which the frame is lengthened is not simply proportional to the load applied. The system acts certainly as a spring, but, constructed with actual practical gyrostats, it has not the properties possessed, though only approximately even in their case, by ordinary springs.

A fair idea of the action, and indeed an approximate realization of the property aimed at, is obtained by means of the arrangement shown in Fig. 7 above. We have had it before. A gyrostat is hung with its axis horizontal by a cord in the same vertical as the centroid. The flywheel spins, but as there is no couple there is no precession. A weight mg is applied in a vertical line at distance l from the centroid, as indicated by the diagram; a slight, very slight, tilting of the gyrostat is produced, and the gyrostat moves off with not quite steady precession, of average angular speed μ. Neglecting the slight deviation, now set up, of the suspension cord from the vertical, and putting A for the moment of inertia of the gyrostat about a vertical axis through its centre, we get for the kinetic energy of the azimuthal motion the value $\frac{1}{2}\mathrm{A}\mu^2 + \frac{1}{2}ml^2\mu^2$. The work done by the weight mg in its descent through the small distance h involved in the tilting is mgh. Hence we get

$$\tfrac{1}{2}(\mathrm{A} + ml^2)\mu^2 = mgh.$$

As we have already seen, however, we have in this case $\mu = mgl/\mathrm{C}n$. Substituting in the equation just found this value for μ, and supposing that A is great in comparison with ml^2, so that the term $\frac{1}{2}ml^2\mu^2$ may be neglected, we find after a little reduction the equation

$$\frac{m}{h} = 2\frac{\mathrm{C}^2 n^2}{\mathrm{A}l^2 g}.$$

Thus h is proportional to m.

It will be evident that if on the right-hand side of the first equation there had been terms due to descent of the gyrostat through a distance of $\frac{1}{4}h$ or $\frac{3}{4}h$, this equation of proportionality could not have been obtained.

The idea, however, underlying the arrangement is very suggestive, and carries us a long way towards obtaining a definite notion as to how the elastic properties of bodies may be explained.

6. Gyrostatic Pendulum.

I have here a pendulum consisting of a rigid suspension rod, and a bob rigidly attached to it, which contains a gyrostat with axis of rotation directed along the suspension rod (Fig. 18). Without rotation, the two freedoms of this system are stable, and if the bob be made to describe a circle about the vertical through the point of support, the period of revolution is the same for both directions of the circular motion. When the gyrostat is spun the behaviour is very different. Circular motion may take place in either direction, but the periods are quite different, that of the circular motion in the same direction as the rotation being the

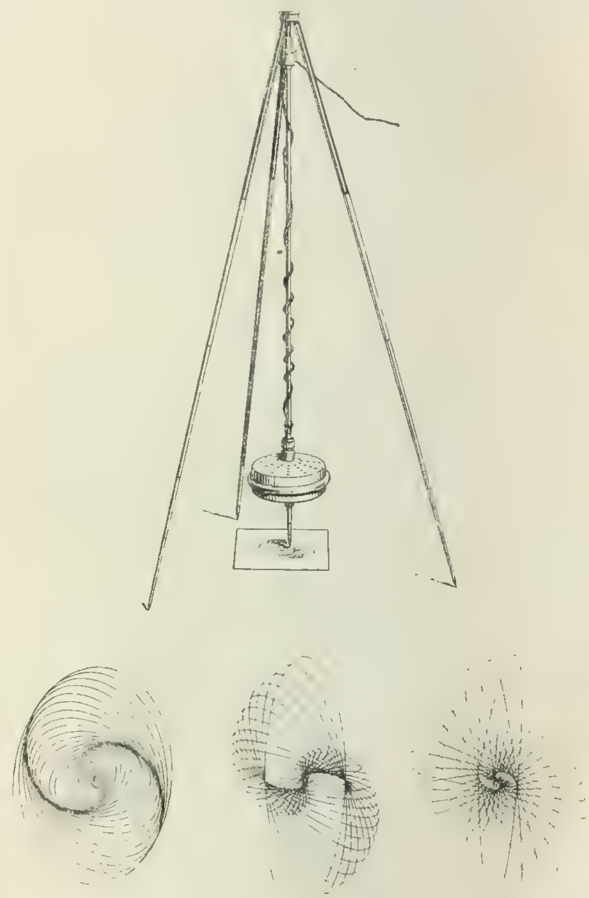


Fig. 18.—Gyrostatic Pendulum and Curves obtained with it.

smaller. Here one period is long, the other comparatively short, a characteristic of all rapidly spinning gyrostatic systems.

A combination of the two circular motions in different periods and in opposite directions gives us a star figure, which in the diagram the pen attached below the bob is shown describing. The peculiar appearance of the graphs here pictured is due to a very rapid falling off of amplitude, and therefore shortening of the rays, due to friction.

The remarkable analogy between the motion of a pendulum with a gyrostat in its bob and the motion of an electron in a magnetic field is dealt with in the Mathematical Appendix. The parallel seems to have occurred to

Lord Kelvin, it was independently pointed out, and by actual trial, by Professor FitzGerald, how Zeeman's discovery was pronounced, and the gyrostatic explanation was thereby rejected by the arrangement of the distinct components of spectral lines which are observed in the Zeeman phenomenon.

7. Vibrations and Waves in Stretched Chain of Gyrostats.

We come now to Lord Kelvin's first mathematical paper on gyrostatics proper, that on "Vibrations and Waves in a Stretched Uniform Chain of Symmetrical Gyrostats." Imagine a chain of straight links like those of a swivelling chain. Let every alternate link be the axis of a flywheel which revolves about the link, and let every flywheel be the same in mass m, and in moment of inertia C about its axis, and rotate with the same angular speed n. We thus have gyrostatic links and connecting links; the length of each gyrostatic link we shall call a, and of each connecting link b; and we shall suppose that the mass of each connecting link is negligible. Imagine each pair of adjacent links to be connected by a Hooke's universal joint, the end of one member of the joint being along the link, the end of the other member along the other link. A mechanical equivalent of the Hooke's joint is a short piece of perfectly flexible, perfectly untwistable wire, rigidly connected at its ends to and in line with the adjacent links.

The chain thus constructed, with the flywheels on it all spinning in the same direction, as seen by an observer looking along the chain from the end A to the end B, is laid with the links all in one plane, and forming an open polygon in that plane, and is then made to turn as a whole with steady angular speed μ round a line A B in the plane, while stretched with a force P directed parallel to A B. It is required to find what must be the form of the polygon, when the inclination of each link to the line A B is small, in order that this steady motion may be possible.

This seems a difficult problem, but the mode of solution is straightforward and easy. The equations of motion of a gyrostatic link, under the forces applied to it by the gyrostatic links at its ends, are easily written down by the principle of the rate of change of angular momentum calculated for moving axes. Two dynamical equations and a geometrical equation are obtained for this representative link, and these are solved by the methods of the calculus of finite differences, so that the positions of the centres of the successive gyrostatic links with reference to the line A B, at any instant, are found. The result is that the centres of these links must lie on a harmonic curve, with the line A B as an axis from which the distances of the centres of the flywheels in the two halves of the curve are equal and opposite, as shown in the diagram.

As this curve of positions of the gyrostats turns round the line A B, the wave form projected on the plane of the paper alternately disappears and reappears reversed. It represents, in fact, a standing wave due to two equal waves travelling along the chain in opposite directions with a certain speed V. Each of these is a wave of circular motion of the gyrostats round the line A B, a circularly polarised wave, in fact. If we suppose the links to be very minute, so that there is a very large number of them in a wave-length of the chain, we can construct the result of propagation and find V, of the propagated wave in a direction perpendicular along a uniform cord stretched with the pull P, and having a mass per unit of length equal to the average mass per unit length of the gyrostatic chain. It is found that if the rotation of the flywheels and the rotation of the whole, about A B, be in the same direction, we may for propagation forward along the chain, have

$$V = V_0 + \frac{\mu}{m a} C n,$$

where m as before, denotes the mass of a gyrostat link and a the link-length. If μ is first greater than V_0, be an assumed proportional to μ as the angular momentum of a single flywheel.

This feature of it is interesting to remark, though Lord Kelvin does not refer to the point, is possible when the chain is under tension: it will stand against this as preventing the motion of flexure in Kelvin's ... (See Appendix, ... [Ed.])

It is readily shown that in which the gyrostats rotate and the whole turns round the line A B in opposite directions, the velocity of propagation is given by

$$V = V_0 - \frac{\mu}{m a} C n.$$

Thus the difference between V and V_0 is numerically the same as in the other case, but has the opposite sign.

From these results we see that an infinite or indeed two circularly polarised waves in which the motions are in opposite directions give a formula of the plane of polarisation of the wave of rectilinear vibration which is the result of their superposition. In a given distance travelled by the two waves in the same direction one turning will gain on the other. The plane of polarisation will turn through half the difference of turning in the two senses. This half difference of angle of turning is Cn/V per unit of distance travelled.

8. Gyrostatic Observation of Rotation of the Earth.

The famous Foucault experiments, Lord Kelvin suggested two ways of determining the rotation of the earth. One was observation of the apparent turning of the plane of vibration of a long pendulum suspended so as to be as nearly as possible free from any constraint due to the attachment of the suspension wire to the fixed support. The classical experiment was carried out with the pendulum at the Pantheon in Paris, and was repeated under the dome of the cathedral of Amiens and Rheims. If the experiment at "Rheims" in Scotland, if many were aware of this fact, it might, they may be justly considered to be just as truly taught as that given by the lofty vaulted roof of the beautiful old church of the ...

Foucault's other method was based on the fact that a gyrostat, if mounted properly, would maintain the direction of its spinning axis, the magnitude and sense unaltered. Here for example is my spinning gyrostat, mounted freely in its containing frame, which is carried by a vertical rod, revolving in a socket, the rod stands upon the supporting stand (see Fig. 8 below). I can set the spinning gyrostat with its axis in any direction (see I spirit), and when I turn the supporting stand round, a friction couple of some little magnitude is applied to the vertical rod. You see that I do not alter the direction

of the spin-axis perceptibly. Yet the friction couple is sufficient to carry the gyrostat round with the stand when there is no spin. The spin results in a great increase of virtual inertia for turning displacements, as we shall see quantitatively in the case of one of Lord Kelvin's experiments, which I am about to describe.

In practice it is found desirable to subject the gyrostatic apparatus to a constraint which is perfectly definite, for example, the axis of spin may be kept horizontal. Solutions of the problem are to be found in the gyrostatic compasses now in use on the warships of various navies.

At the British Association Meetings at Southport and Montreal, in 1883 and 1884, Lord Kelvin suggested methods of demonstrating the earth's rotation, and of constructing a gyrostatic compass. One of these had reference to the component of rotation about the vertical, the component in fact demonstrated by the Foucault pendulum experiment. If ω be the resultant angular speed the component about the vertical at any place in latitude l is $\omega \sin l$, while the companion component about the horizontal there is $\omega \cos l$. Thus at London the component about the vertical is 0·78 of ω, and the period of rotation about the vertical is about 30·77 hours of sidereal time. (One sidereal day = 86,160 seconds, nearly.)

Lord Kelvin's method of measuring $\omega \sin l$ consists in supporting a gyrostat on knife-edges attached to the projecting edge of the case, so that the gyrostat without spin rests with the axis horizontal or nearly so. For this purpose the line of knife-edges is laid through the centre of the flywheel at right angles to the axis, and the plane of the knife-edges is therefore the plane of symmetry of the flywheel perpendicular to the axis. The knife-edges are a little above the centre of gravity of the instrument which we suppose in or nearly in that plane, so that there is a little gravitational stability. The azimuth of the axis is a matter of indifference, as any couple due to the component of rotation about the horizontal is balanced by an equal couple furnished by the knife-edge bearings.

At points in a line at right angles to the line of knife-edges, and passing through it, two scale-pans are attached to the frame-work, and by weights in these the axis of the gyrostat (without spin) is adjusted, as nearly as may be, in a horizontal position which is marked. The gyrostat is now removed, to have its flywheel spun rapidly, and is then replaced. It is found that the weights in the scale-pans have to be altered now to bring the gyrostat back to the marked position. From the alteration in the weights the angular speed about the vertical can be calculated.

To fix the ideas let the gyrostat axis be north and south, and let the spin to an observer, looking at it from beyond the north end, be in the counter-clock, or positive direction. The rotation of the earth about the vertical carries the north end of the axis round towards the west, and therefore angular momentum is being produced about a horizontal axis drawn westward, at a rate equal to $C n \omega \sin l$, where C is the angular momentum of the flywheel. If the sum of the increase of weight on one scale-pan and the diminution (if any) in the other be w, and a be the horizontal distance between the points of attachment of the scale-pans, we have

$$C n \omega \sin l = w g a.$$

Thus if C and n are known, $\omega \sin l$, or ω, can be calculated.

Lord Kelvin does not give any figures as to the forces to be measured in a practical experiment; but I can supply these. We may take the mass of a small flywheel as 400 grammes, its radius of gyration as 4 cm., and its speed of revolution if high as 200 revolutions per second. If we take a as 10 cm. we obtain for London the equation

$$400 \times 4^2 \times 400 \pi \times \frac{2\pi \times 0{\cdot}78}{86160} = 10 \times 981 \times w.$$

This gives $w = 0{\cdot}047$ gramme, or 47 milligrammes. It would require careful arrangements to carry out the experiment accurately, but the idea is clearly not unpractical. With some of the new gyrostats that we now have, the mass of the wheel is as much as 2,000 grammes, and the radius of gyration is about 7·5 cm. These numbers bring w up to 0·82 gramme, at the same speed.

If the gravitational stability of this gyrostatic balance be removed, that is, the line of knife-edges be made to pass accurately through the centre of gravity of the system of wheel and framework, and the axis of rotation be placed in a truly north and south vertical plane, so that the knife-edges are horizontally east and west, the gyrostat will be in stable equilibrium when the axis is parallel to the earth's axis, and is turned so that the direction of rotation agrees with the rotation of the earth. For we have then simply the experiment, described above, of the gyrostat mounted on trunnions resting on bearings attached to a tray which is carried round by the experimenter. The axis of the gyrostat was at right angles to the tray, and we saw that when the tray, held horizontally, was carried round in azimuth the equilibrium of the gyrostat was stable or unstable, according as the two turnings agreed or disagreed in direction. In the present case the tray is the earth, the position of the axis of rotation parallel to the earth's axis replaces the vertical position, and the earth's turning the azimuthal motion. If displaced from the stable position the gyrostat will oscillate about it in the period $2\pi\sqrt{A/Cn\omega}$, where A is the moment of inertia about the knife-edges, and the other quantities have the meanings already assigned to them.

If the line of knife-edges be north and south, the vertical will be the stable, or unstable, direction of the axis of rotation, and there will be oscillation about the stable position in the period $2\pi\sqrt{A/Cn\omega \sin l}$.

The gyrostat thus imitates exactly the behaviour of a dipping needle in the earth's magnetic field, and thus we have Lord Kelvin's gyrostatic model of the dipping needle.

It is right to point out that these arrangements were anticipated by Gilbert's Barogyroscope,* which rests on precisely the same idea, and applies it in a similar manner.

9. Gyrostatic Compass.

At Montreal Lord Kelvin described a "Gyrostatic Model of a Magnetic Compass." This was one of his gyrostats hung, with its axis of rotation horizontal, by a long fine wire attached to the framework at a point over the centre of gravity of the system, and held at the upper end by a torsion-head capable of being turned round the axis of the wire. By means of this torsion-head any swinging of the gyrostat in azimuth round the wire was to be checked

* "Mémoires sur divers problèmes," etc. *Annales de la Société Scientifique Bruxelles*, 1877–8.

[illegible]

[illegible] before. The coexistence of long and short periods is, how- [illegible]

[illegible] torsional rigidity that this rigidity cannot stabilize the gyrostat in the position of unstable equilibrium. Then the effect of the component of rotation of the earth about the vertical is to produce tilting of the axis of the flywheel from the horizontal position, since this turning gives a rate of production of angular momentum about a horizontal axis at right angles to that of rotation. A slight tilt suffices to give an equilibrating couple, and so we can have the gyrostatic axis in a north and south vertical plane, and nearly horizontal, while the wire is without twist. Into [illegible] torsion-head. The effect of the horizontal component of the earth's angular speed is now practically zero.

If now by the use of the torsion-head the gyrostat axis be brought to rest in a nearly horizontal position at an angle ϕ with the north and south horizontal direction, the component of turning about this position of the axis is $\omega \cos l \cos \phi$, and about a horizontal line at right angles to the new position of the axis is $\omega \cos l \sin \phi$. The former has no influence on the gyrostatic axis, the latter gives a rate of production of angular momentum about the vertical [illegible] equal to this must be applied by means of the torsion-head to produce equilibrium, and this as we see is proportional [illegible]

I remember that I spent a good deal of time about 1884 in the Glasgow Laboratory trying, without much success, to realize this arrangement. Lord Kelvin himself sug- [illegible] of inertia of the gyrostat when vibrating about the vertical wire there would be difficulty in realizing the arrangement, and he concluded his paper at Montreal by referring to a simplified manner of realizing a gyrostatic compass, free only to move in a horizontal or nearly horizontal [illegible]

[illegible]

[illegible]

[illegible] also expanded in the same way on the proof sheets [illegible] skill of the most expert analyst, for questions arise regarding the roots of the determinantal equations and their interpretation, which require great care in handling. I may only quote the general conclusions as to gyrostatic domination.

[illegible] freedoms exclusive of those by which the flywheels have [illegible] of the system when at rest (without spin of the flywheels) be either stable, or unstable, for every freedom. If the wheels are so linked up to the system as to render gyrostatic domination possible, then with sufficiently rapid spin the equilibrium becomes stable, with half the whole number, $2n$ say, of its periods of vibration exceedingly small, and the other half very large. Each set of periods is given by the roots of a determinantal equation of [illegible] were called "adynamic," the former periods were called "precessional" and do depend on the applied forces.

The first approximations to the fast and slow azimuthal motion of a top are in point. The angular speed $Cn/A \cos \theta$ [illegible]

[illegible] Models. Conclusion.

[illegible] electricity and magnetism, and in all of them he ever sought [illegible] and magnetism are highly dynamical affairs; we send signals by wire or "wireless," we transmit power in a wonderful manner by an agency which we are still far from com- [illegible]

lated in full detail, but to a considerable extent already correctly comprehended.

The electromagnetic theory of light, and later the great mass of complicated effects which depend on the existence and play of electrons, have, however, made it necessary for every student to re-orient himself, as it were, and consider over again all the old categories and hypotheses. A new series of conceptions must be grappled with, and so, instead of a more or less apparently complete working model of ether, capable of explaining, or rather accounting for the phenomena, all that we can hope for is to find some kind of correspondence between the "engines of orbs" which great men have imagined, and electrical and magnetic processes. The only way is to study more and more intently the phenomena, for it is only the phenomena that manifest realities, they are for us *the* realities. "The reality behind the phenomena," the "Ding an sich," may be an important affair in philosophy, but as far as I can see its pursuit is not likely to be fruitful in science.

Of course it is important to theorize, if we are to unify the diversity of phenomena, if we are to be scientific, that is science-making. As always, agreement with all the facts is the true test of a theory, so far as our knowledge goes; if besides the theory is predictive, its probability is raised to a still higher plane. It must, however, fulfil all tests; if it does not it must be given up. I will close by calling attention in this connection to a remarkable utterance of Lord Kelvin about eight years before his death. In a paper of date 17 July, 1899, on "Magnetism and Molecular Rotation" which appeared in the *Philosophical Magazine** he formally surrendered his favourite gyrostatic theory so far as it seemed to relate to the action of a magnetic field on light vibrations. Zeeman's discovery of the splitting up of each bright line into a definite complex of lines by the action of a magnetic field could not be accounted for by any scheme of infinitesimal gyrostats. On the contrary, the different inclinations of the axes of the gyrostats to the direction of the field ought merely to result in a general broadening of the original lines, not always in the definite tripling or further multiplication which is observed. This had been pointed out in 1897 by Larmor in his remarkable paper on Zeeman's† discovery that "A principal oscillator magnetically tripled must be capable of being excited with reference to any axis in the molecule: otherwise there would be merely hazy broadening or duplication instead of definite triplication."

This Lord Kelvin admitted was conclusive against the gyrostatic theory so far as the Zeeman effect was concerned; but he was still disposed to retain it for the explanation of "Faraday's Diamagnetism." Whether this position is tenable or not time will decide, perhaps has already decided.

Lord Kelvin certainly had confidence in his own theories and clung firmly to his conclusions. He was *tenax propositi*, yet he could on occasion acknowledge that he had made a mistake. His genius ranged over the whole field of physical science, no problem was too great or too small to attract his attention. No obstacles, no complications, daunted his spirit of enquiry. The thunders of Jove, the birth of the world and the cold death prepared for it by dissipation of energy, the harnessing of the energies of nature for the service of man, the guidance and safety of mariners, the genesis of waves and their breaking into spray and spindrift, all these questions, and many others, engaged his thoughts, to the lasting benefit of humanity and the increase of knowledge. Throughout all he was keen and calm and dispassionate, a truly unaggressive and kindly natural philosopher.

The function of science is to enable man to penetrate the secrets of Nature, and to apply that knowledge to the promotion of the welfare and happiness of all living beings. No one would have repudiated with more scorn than Lord Kelvin that emanation of the Pit, the modern doctrine that culture, scientific, philosophical, or artistic, entitles a self-appraised and self-chosen nation to wade through seas of blood to the domination of the world.

* *Philosophical Magazine*, vol. 48, p. 236, 1899.
† *Ibid.*, vol. 44, p. 55, 1897.

MATHEMATICAL APPENDIX.

(1) *Double pendulum with revolving support.*—The equations of motion in § 2 are easily obtained. Let the axes Ox, Oy revolving in their own plane with angular speed ω in the counter-clock direction, coincide at the instant considered with fixed axes Oa, Ob. The co-ordinates of the bob are x, y. In consequence of the turning the co-ordinates y and x give speeds of the bob $-\omega y$ and ωx parallel to Ox and Oy respectively. Hence the speeds u, v along Oa, Ob are $u = \dot{x} - \omega y$, $v = \dot{y} + \omega x$. Similarly the accelerations are $\dot{u} - \omega v$, $\dot{v} + \omega u$, or $\ddot{x} - 2\omega\dot{y} - \omega^2 x$, $\ddot{y} + 2\omega\dot{x} - \omega^2 y$.

Now the component forces applied by the cord along Ox, Oy are $-mgx/l$, $-mgy/l'$. Hence we get the equations of motion

$$\ddot{x} - 2\omega\dot{y} + \left(\frac{g}{l} - \omega^2\right)x = 0,\quad \ddot{y} + 2\omega\dot{x} + \left(\frac{g}{l'} - \omega^2\right)y = 0 \quad . \ (1)$$

To integrate (1) assume $x = a\epsilon^{int}$, $y = b\epsilon^{int}$, where $i = \sqrt{-1}$, and substitute. We get

$$\left.\begin{array}{r} a\left(\omega^2 + n^2 - \dfrac{g}{l}\right) + 2b\omega i n = 0 \\ -2a\omega i n + b\left(\omega^2 + n^2 - \dfrac{g}{l'}\right) = 0 \end{array}\right\} \quad . \ . \ . \ (2)$$

Putting $g/l = \mu^2 + \lambda^2$, $g/l' = \mu^2 - \lambda^2$ (so that λ^2 is very small when l and l' are nearly equal) we get from (2)

$$\frac{a}{b} = i\sqrt{\frac{n^2 + \omega^2 - \mu^2 + \lambda^2}{n^2 + \omega^2 - \mu^2 - \lambda^2}} = i\rho, \text{ say,} \quad . \ . \ (3)$$

where of course i may have either sign, to correspond to that used in the values assumed above for x, y. From (3) and (2) it follows that

$$\rho = \frac{-2\omega n}{\omega^2 + n^2 - \mu^2 - \lambda^2} = -\frac{\omega^2 + n^2 - \mu^2 + \lambda^2}{2\omega n} \quad . \ (3')$$

Thus there is a value of ρ for each value of n^2; these can be found by (5) below. We shall denote them by ρ_1, ρ_2.

Also by elimination of a and b from (2) we obtain the quadratic in n^2

$$n^4 - 2(\omega^2 + \mu^2)n^2 - 2\omega^2\mu^2 + \omega^4 + \mu^4 - \lambda^4 = 0, \ . \quad (4)$$

of which the roots are given by

$$n^2 = \omega^2 + \mu^2 \pm \sqrt{4\omega^2\mu^2 + \lambda^4} \quad . \ . \ . \ . \ (5)$$

[illegible]

$$[illegible] \qquad (6)$$

[illegible]

of stable motion are exactly of the form (1), but with the [illegible]

[illegible]

$$[illegible] \qquad (7)$$

where the upper signs apply to n_1, the lower to n_2. It will [illegible] more if both of these provisos hold,

$$\frac{n_1}{n_2} = \omega \pm a \qquad (8)$$

It may be verified that the complete solution of (1) is

$$[illegible] \qquad (9)$$

where ρ_1, ρ_2 have the values indicated in (3′), and a_1, β_1, [illegible] are constants. Now each ρ is negative or positive according as n is positive or negative. Taking the former case and [illegible] that ω is very great we have, [illegible] If we suppose [illegible] we obtain

$$[illegible] \qquad (9')$$

To interpret this solution refer to fixed rectangular axes [illegible] We have

$$\xi = x \cos \omega t - y \sin \omega t, \quad \eta = x \sin \omega t + y \cos \omega t$$

[illegible]

The terms in a_1 give a circular motion of period $2\pi/a$, in the [illegible] direction to the rotation, [illegible] same [illegible] of period [illegible] in the same direction as the rotation. The former is the longer period.

[illegible]

which [illegible] transverse directions at right angles to [illegible]

[illegible] Lord Kelvin's mathematical papers on Gyr[illegible] the general results are summarized in the Lecture, I set down here a statement of the theory of a single gyrostat, using a simple vectorial method, which occurred to me [illegible] such cases.

[illegible] about the point O, with angular speed ω, in the direction [illegible]

FIG. [illegible]

[illegible] angular speed ω, while Om is moving away from the [illegible] For clearness we shall denote these instantaneous positions [illegible]

Now let L, M be directed quantities of the same kind, [illegible]

$$L - M\omega, \quad M + L\omega$$

respectively.

For let $\mathbf{H}$ be a [illegible] $\mathbf{H}$ [illegible]

time $t + d\,t$ let the vector be represented in magnitude and direction by O h'. Then $h\,h'$ represents in magnitude and direction the change d **H** in the vector **H** that has grown up in the interval $d\,t$, and we have $d\,\mathbf{H} = \dot{\mathbf{H}}\,d\,t$, where $\dot{\mathbf{H}}$ denotes the rate of vector growth.

But d **H** is compounded of the two vectors represented by $h\,k$ and $k\,h'$. The angle h O h' is $\omega\,d\,t$, where ω is the rate of turning of direction. Hence the magnitude of $h\,k = H\,\omega\,d\,t$, and the magnitude of $k\,h' = \dot{H}\,d\,t$. The former is in the forward direction at right angles to O h,

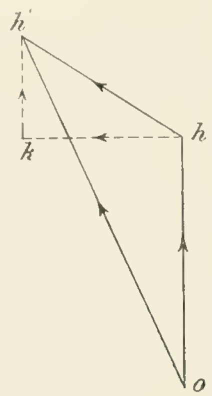


FIG. 20.

the other is in the original direction O h. The rates of change of magnitude in these directions are $H\,\omega$ and $\dot{H}$ respectively.

This analysis is applicable to any number of coexistent moving vectors, for example to the two vectors L, M turning round O (Fig. 19). Thus we get for the total rate of growth of vector magnitude along O m, in that case $\dot{\mathrm{M}} + \mathrm{L}\,\omega$, and along O l_1, $\dot{\mathrm{L}} - \mathrm{M}\,\omega$.

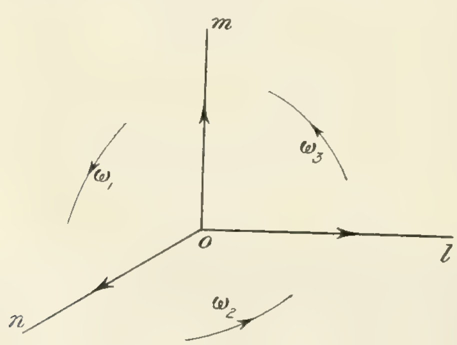


FIG. 21.

In the same way if we have three vectors (of magnitudes L, M, N) represented by O l, O m, O n (Fig. 21), three lines mutually at right angles, and these be turning as shown in the diagram, that is the two O m, O n about O l with angular speed ω_1, the two O n, O l about O m with angular speed ω_2, and the two O l, O m about O n with angular speed ω_3, the total rates of growth of vectorial magnitude for three fixed directions O l_1, O m_1, O n_1 with which the moving axes at the instant coincide are respectively

$$\dot{L} - \omega_3 M + \omega_2 N,\ \ \dot{M} - \omega_1 N + \omega_3 L,\ \ \dot{N} - \omega_2 L + \omega_1 M.$$

The values of the quantities ω_1, ω_2, ω_3, L, M, N will be settled by the circumstances of the different cases. The signs to be placed before terms ω_2 N, etc., will be at once determined by observing whether the vector producing the term is turning *towards* or *away from* the direction for which the rate of change is being found. In the former case the positive sign, in the latter the negative sign, is to be prefixed to the term.

(3) *Theory of a single gyrostat.*—A gyrostat is a flywheel enclosed in a case or framework, which is, as nearly as may be, symmetrical about the axis of the wheel. The main part of the mass of the flywheel is collected in its rim, so that the moment of inertia about the axis is made as great as possible in proportion to the whole mass of the revolving part. The case may be constrained to move in any specified manner, while the flywheel rotates in the interior with an angular speed, which, if there were no friction at the bearings and no resistance due to air within the case, would be invariable. We shall suppose for the present that this angular speed does not change; but it is

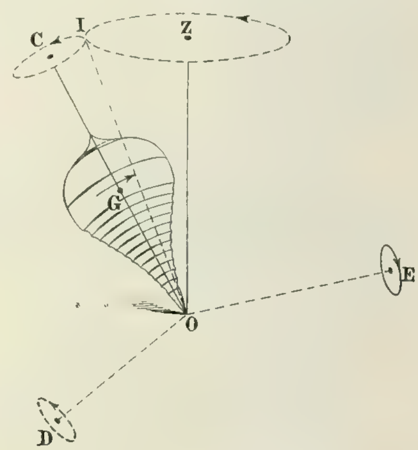


FIG. 22.

to be remembered that in many practical applications the falling away of the speed of rotation must be reckoned with. The diagrams shown in the lecture (see Figs. 5, 9, 12, 13) give the construction of the Kelvin instruments.

In this diagram (Fig. 22) the position of the top represents that of the flywheel of a gyrostat with respect to a known axis of co-ordinates O Z (in many practical cases the vertical) about which in many problems the gyrostat is supposed to be turning with angular speed $\dot{\psi}$. The axis of rotation of the wheel, O C in the diagram, which is also the axis of symmetry of the whole arrangement, intersects O Z in O, which is not here necessarily a point fixed in space. We take the centre of gravity G of the gyrostat and case as origin of co-ordinates, and choose axes G C along the axis of figure, G D at right angles to the plane of G C and O Z, and a third axis G E in that plane, and perpendicular to the other two. [The latter two axes are parallel to the two O D, O E, which are shown in the diagram, and which in many cases, when O is a fixed point, it is convenient to use.] These axes move with the plane of O Z and O C; and we consider also fixed axes G C_1, G D_1, G E_1 with which at the instant considered the moving axes coincide, and

[illegible] momentum. [illegible] time t, are no longer coincident at time $t + dt$, and the time rates of change for the fixed axes and those for the moving axes are in general not the same.

The axes G C, G D, G E, and the [illegible] axes G C, G D, G E, form an ordinary system of rectangular axes, and angular momenta, or angular speeds, about them have the directions shown by the [illegible] arrow heads round O C, O D, O E in the diagram.

[illegible] case, be each measured round the axis of figure. If the [illegible] the vertical with angular speed $\dot\psi$, and θ denote the angle [illegible] the axes G D, G E are turning about the axis of figure with angular speed $\dot\psi \cos\theta$, [illegible] about G E with angular speed $\dot\psi \sin\theta$, and about G D with angular speed $\dot\theta$. The angular speed n is made up of $\dot\psi \cos\theta$ due to the motion of the plane G O Z and the angular speed n' with which the flywheel turns relatively to that plane. In the same way ω may be put equal to $\dot\psi \cos\theta + \omega'$, where ω' is the angular speed of the case relatively to the same plane. We put ω_1 for the angular speed of the case about G E. Hence if the case simply turn with the plane G O Z, ω' is zero, and $\omega_1 = \dot\psi \sin\theta$.

The components of angular momentum of the gyrostat are $C n + C' \omega$, about G C, $A \dot\theta$ about G D, and $A \omega_1$ about G E, where C, C' are the moments of inertia of the flywheel and case about the axis of figure. The axes turn with angular speeds $\dot\psi \cos\theta$ about G C, $\dot\theta$ about G D, and $\dot\psi \sin\theta$ about G E.

Now for the rate of growth of angular momentum about the fixed axis G D_1, with which, at time t, G D coincides, we have first the term $A \ddot\theta$. Next there are two contributions arising from the motions of the axes G C, G E. They are respectively $(C n + C' \omega) \dot\psi \sin\theta$, $- A \omega_1 \dot\psi \cos\theta$, since the axis G C is approaching G D while G E is being carried farther away from that axis. Hence the whole rate of growth is

$$A \ddot\theta + (C n + C' \omega) \dot\psi \sin\theta - A \omega_1 \dot\psi \cos\theta.$$

This is equal to the moment of the couple, G say, applied about G D_1, and thus we get the equation of motion

$$A \ddot\theta + (C n + C' \omega) \dot\psi \sin\theta - A \omega_1 \dot\psi \cos\theta = G \quad . \quad (1)$$

[illegible]

$$[illegible] \quad . \quad (2)$$

We have additional equations arising from the motion of G, which, in the important case in which the point O on the axis is fixed, reduce to the single equation

$$M [illegible] = F \quad . \quad (3)$$

[illegible]

In the same way we obtain the equation of motion for [illegible] couple to be H. The equation of [illegible]

$$[illegible] = H \quad . \quad . \quad (4)$$

[illegible]

$$[illegible] \quad (5)$$

[illegible]

$$[illegible] \quad (6)$$

Finally for the axis of figure we have two equations first

$$[illegible] \quad (7)$$

since we suppose the friction couple on the bearings of the flywheel to be negligible, and second

$$[illegible] \quad (8)$$

if R be the moment of the couple acting on the case about the axis of figure.

It may be remarked here that the energy equation is

$$\tfrac{1}{2}(M [illegible] + C n^2 + C' \omega^2 + A \dot\theta^2 + A \omega_1^2) [illegible] \quad (9)$$

For the top spinning about a fixed point on the axis of figure there is an equation of constancy of angular momentum, namely

$$[illegible] = L \quad . \quad (10)$$

where L is the angular momentum about the vertical.

[illegible] is the whole mass, and h is the distance of the centre of gravity from the point of support. Hence [illegible]

$$[illegible] = M g h \sin\theta \quad . \quad (11)$$

In this equation A [illegible] moment of inertia about an axis transverse to O C through O, the fixed point.

[illegible]

motion value of $\dot{\psi}$, we get, since the condition for steady motion is $\dot{\mu} = 0$, $\dot{\theta} = 0$,

$$(C\,n + C'\,\omega_1 - A\,\mu\cos\theta)\,\mu\sin\theta = M\,g\,h\sin\theta \quad . \quad (1)$$

Since the motion is steady $C'\,\omega_1$ must be constant, and so we may regard this term as included in C n, so that

$$(C\,n - A\,\mu\cos\theta)\,\mu\sin\theta = M\,g\,h\sin\theta \quad . \quad . \quad . \quad (2)$$

If θ is not zero this equation can only be satisfied by the condition

$$(C\,n - A\,\mu\cos\theta)\,\mu = M\,g\,h$$

or

$$A\cos\theta\,.\,\mu^2 - C\,n\,\mu + M\,g\,h = 0 \quad . \quad . \quad . \quad (3)$$

The roots of this equation are real if $C^2n^2 > 4\,A\,M\,g\,h\cos\theta$. Unless this condition is fulfilled steady motion is not possible. For example, a top cannot spin upright unless $C^2n^2 > 4\,A\,M\,g\,h$.

The sum of the roots of (3) is $C\,n/A\cos\theta$, and their product is $M\,g\,h/A\cos\theta$, and therefore if C n be very great there is a large root and a small one. The latter is given to a first approximation by disregard of the term in μ^2, so that

$$\mu = \frac{M\,g\,h}{C\,n} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

The former is given also to a first approximation by disregard of the term M $g\,h$, and we have

$$\mu = \frac{C\,n}{A\cos\theta} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

The root given in (5) is very approximately correct when n is very great, that is when C n is very great in comparison with M $g\,h$. It then arises from the very nearly exact compensation of the rate of growth of angular momentum $C\,n\,\mu\sin\theta$ (due to the turning of the axis O C towards the instantaneous position of O D, with angular speed $\mu\sin\theta$ about O E) by the rate of growth $-A\,\mu^2\cos\theta\sin\theta$ (due to the turning of O E away from the instantaneous position of O D, with angular speed $\mu\cos\theta$ about O C).

To carry these approximations to any desired higher degree of accuracy, write a for $Cn/A\cos\theta$, b for $Mgh/A\cos\theta$. The quadratic (3) becomes

$$\mu^2 - a\,\mu + b = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

We can express this as a continued fraction for the calculation of the small root. We have

$$\mu = \frac{b}{a-\mu} = \frac{b}{a-}\,\frac{b}{a-\mu} = \frac{b}{a-}\,\frac{b}{a-}\,\frac{b}{a-\mu}, \quad . \quad (7)$$

and so on. For example, take the second approximation,

$$\mu = \frac{b}{a-}\,\frac{b}{a} = \cfrac{b}{a - \cfrac{b}{a}} = \frac{a\,b}{a^2 - b}.$$

This gives

$$\mu = \frac{M\,g\,h}{C\,n}\left(1 + \frac{M\,g\,h\,A\cos\theta}{C^2n^2}\right) \quad . \quad . \quad . \quad . \quad (8)$$

The third approximation,

$$\mu = \frac{b}{a-}\,\frac{b}{a-}\,\frac{b}{a} = \frac{b}{a}\left(1 + \frac{b}{a^2} + 2\frac{b^2}{a^4}\right),$$

gives

$$\mu = \frac{M\,g\,h}{C\,n}\left(1 + \frac{M\,g\,h\,A\cos\theta}{C^2n^2} - 2\frac{M^2g^2h^2A^2\cos^2\theta}{C^4n^4}\right) \quad (9)$$

Since the sum of the roots is $C\,n/A\cos\theta$, the successive approximations to the large root are obtained by subtracting the values obtained for the small root from this quantity. We have therefore

$$\left.\begin{aligned}
&\mu = \frac{C\,n}{A\cos\theta}, \qquad \mu = \frac{C\,n}{A\cos\theta} - \frac{M\,g\,h}{C\,n}\\
&\mu = \frac{C\,n}{A\cos\theta} - \frac{M\,g\,h}{C\,n}\left(1 + \frac{M\,g\,h\,A\cos\theta}{C^2n^2}\right)\\
&\mu = \frac{C\,n}{A\cos\theta} - \frac{M\,g\,h}{C\,n}\left(1 + \frac{M\,g\,h\,A\cos\theta}{C^2n^2} - 2\frac{M^2g^2h^2A^2\cos^2\theta}{C^4n^4}\right)
\end{aligned}\right\} \quad . \quad (10)$$

These are, of course, also the values obtained by the other continued fraction form of (3) given by

$$\mu = a - \frac{b}{\mu}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

that is

$$\mu = a - \frac{b}{a-}\,\frac{b}{a-}\,\frac{b}{a-}\cdots \quad . \quad . \quad . \quad . \quad (12)$$

From the discussion given above it will be seen that if $\theta = \frac{1}{2}\pi$, the larger root of the steady motion equation (3)

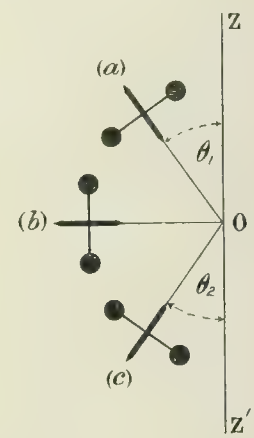


FIG. 23.

is infinite, so that there is only one realizable value of μ, that is $\mu = M\,g\,h/C\,n$. If θ be greater than $\frac{1}{2}\pi$, the value of the larger root $C\,n/A\cos\theta$ is negative. Thus take the three positions of the gyrostat shown in the diagram (Fig. 23). If the direction of rotation of the flywheel be the same in all three (that is counter-clockwise as viewed by an eye looking towards O along the axis of rotation from the side of the gyrostat remote from O) the direction of the precession measured by the root which is approximately $M\,gh/C\,n$ is counter-clockwise, to an eye looking towards O from Z, for all three cases. The turning motion given by the other approximate root is, when looked at in the same way, in the counter-clock direction in case (a), and is reckoned positive; in case (b) it is $+\infty$ when the angle Z O C is infinitely little less than $\frac{1}{2}\pi$, and is $-\infty$ when that angle is infinitely little greater than $\frac{1}{2}\pi$, and in case (c) for which the angle Z O C is between $\frac{1}{2}\pi$ and π it is negative, that is clockwise, and of numerical value $C\,n/A\cos\theta_2$.

It will be observed that if small quantities be neglected the large root is independent of the applied couple. Thus

[illegible]

that the excess of kinetic energy at the lower circle above [illegible] the azimuthal motion there.

[illegible] lations from limiting circle to limiting circle are very [illegible] out completely by the theory of elliptic functions.

The general theory shows that if a system have an even number $2n$ of freedoms, all unstable or all stable without spin, the system if unstable before spin is completely [illegible] by another equation of the nth degree. The latter, if the [illegible]

[illegible] ing the applied couple $M g h \sin \theta$. Going back to (3) let [illegible]

[illegible] the value μ of the precession under the enhanced couple is given by

[illegible]

[illegible]

The increase of couple thus diminishes the large root [illegible]

[illegible] about the steady motion. If this [illegible] cordance with fact, the anal [illegible] the disturbed value corresponding to $\theta_0 + \alpha$. Since in the [illegible]

[illegible]

where U is what the expression

[illegible]

[illegible] since the changes are small (1) becomes

[illegible]

we obtain easily

[illegible]

[illegible] period

$$T = [illegible]$$

The disturbance has been supposed such as to leave equation (11) § (3) still applicable, or what amounts to the same thing, leave the angular momentum about the vertical unchanged; for example, a small vertical impulse would fulfil the condition. But a similar result would be obtained for any small disturbance, as can easily be verified.

It may be noticed that if the top is spun very fast so that the smaller value of the angular speed (approximately $M g h / C n$) is very small, the period of oscillation about the steady motion with this value of μ is approximately $2 \pi A / C n$. This may be verified from (5), or by neglecting all the terms in the brackets in (2) except $C n$, and using $A \sin \theta_0 \, d\psi / d\theta = C n$, instead of (3), when the result follows at once. This approximation to the period is independent of θ.

Again, if the top is spun very fast, the period of oscillation about the steady motion for the large value of μ is approximately $2 \pi / \mu$, that is the period of revolution of the

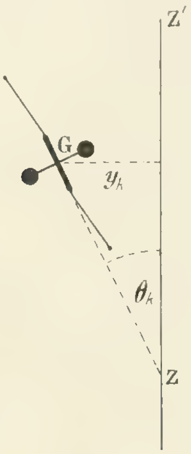


FIG. 24.

axis in the precessional cone. This follows from (5), because then the denominator on the right becomes $A \mu^2$ very nearly, so that $T = 2 \pi / \mu$. Thus in one half of the revolution the axis is above the steady motion position, in the other half below it. This period is $2 \pi A \cos \theta / C n$. For $\theta = 0$, the upright position, it agrees with the other period, and varies from that to zero for different values of θ from 0 to $\frac{1}{2} \pi$.

(6) *Problem of stretched chain of gyrostats.*—We can now apply these equations in particular cases, and we take first Lord Kelvin's problem of the stretched chain of gyrostats. The chain consists of equal gyrostatic links alternating with ordinary rigid connecting links all of the same length and supposed to be of negligible mass. In Lord Kelvin's scheme the connection at each junction is made by a universal flexure (Hooke's) joint, and the chain forms an open plane polygon held at its extremities A, B, in the line $Z Z'$ (Fig. 24), by joints of the same kind, and the whole turns with uniform angular speed μ, without change of configuration about the line A B. It is required to find the form of the chain, when the inclination of each link to the line A B is very small.

A gyrostatic link, the kth in order, which we shall refer to as L_k, is indicated in the diagram (Fig. 24) with the connecting links at its ends, which we shall denote by l_k, l_{k+1}. [It is to be remembered in what follows that the line A B and the line $Z Z'$ of the diagram are the same.] The length of each L is a, and of each l is b. We put θ_k for the inclination of the axis of L_k to A B, ϕ_k, ϕ_{k+1} for the inclinations of l_k, l_{k+1} to the same line, y_k for the distance of the centroid (the centre) of L_k from the line A B, and m for the mass of L_k. We proceed at once to the case in which the angles here specified are all very small.

We get first the geometrical equation

$$y_{k+1} - y_k = \tfrac{1}{2} a (\theta_{k+1} + \theta_k) + b \phi_{k+1} \quad . \quad . \quad . \quad (1)$$

Next if P be the component parallel to A B of the pull along a link, we easily see that for equilibrium this must be the same for every link. The component of pull at right angles to A B is $P \tan \phi_k = P \phi_k$. We obtain the equation for the acceleration of the centroid of L_k as it moves in its circular path about A B with angular speed μ

$$m \mu^2 y_k = P (\phi_k - \phi_{k+1}) \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Finally we obtain the gyrostatic equation [see (2), § (3) above]

$$A \ddot{\theta}_k + (C n + C' \omega_1 - A \mu) \mu \theta_k = \tfrac{1}{2} P a (\phi_{k+1} + \phi_k - 2 \theta_k) \quad (3)$$

The quantity on the right is the approximate value of the moment of the forces on L_k taken about an axis through the centroid of L_k at right angles to the plane of the polygon, an axis corresponding to $G D_1$ of § (3) above. [The exact value of the moment is

$$\tfrac{1}{2} P a \left\{ (\tan \phi_{k+1} + \tan \phi_k) \cos \theta_k - 2 \sin \theta_k \right\}]$$

The only quantity undetermined in this equation, (3), is ω_1. This is given by the geometry of the Hooke's joint, which is equivalent in its action to a short piece of quite flexible but untwistable wire connecting the adjacent links. Each L when thus joined behaves as if the gyrostatic axis were prolonged to intersect the line A B, and were there held by such a piece of wire in line at one end with B A and at the other with L. The instantaneous axis about which L_k turns bisects the angle supplementary to θ_k. If ω be the angular speed of L_k about this axis, we have

$$\omega \sin \tfrac{1}{2} (\pi - \theta_k) = \mu \sin \theta_k$$

or

$$\omega = 2 \mu \sin \tfrac{1}{2} \theta_k \quad . \quad . \quad . \quad . \quad . \quad (4)$$

This resolves into a component $2 \mu \sin^2 \frac{1}{2} \theta_k \; [= \mu (1 - \cos \theta_k)]$ about the axis of L_k, and a component $\mu \sin \theta_k$ about the axis G E (§ (3)) drawn in the plane of the polygon at right angles to the axis of L_k. Hence $\omega_1 = 2 \mu \sin^2 \frac{1}{2} \theta_k$, which is negligible when θ_k is very small. Even if this angular speed were not negligible the smallness of C' would render the term $C' \omega_1$ inappreciable. The precise mode of connection is thus of no consequence. It is, however, to be remembered that the angular speed μ about A B gives a component $\mu \cos \theta_k$ about the axis of L_k by which the turning of the axis G E is to be reckoned, and a component $\mu \sin \theta_k$ about G E which gives the turning of the axis of the flywheel towards $G D_1$. Equation (3) thus becomes

$$A \ddot{\theta}_k + (C n - A \mu) \mu \theta_k = \tfrac{1}{2} P a (\phi_{k+1} + \phi_k - 2 \theta_k) \quad . \quad (5)$$

[illegible]

$$[illegible] \qquad (7)$$

[illegible]

$$E = \cos\alpha \pm \iota\sin\alpha \qquad (9)$$

and therefore,

$$[illegible] \qquad (10)$$

[illegible]

$$y_s = A\cos s\alpha + B\sin s\alpha \qquad (11)$$

If x_s denote the co-ordinate parallel to A B measured from the centre of the link L_s, we have

$$x_s = s(a+b)$$

so that (11) becomes

$$y_s = A\cos\frac{\alpha x_s}{a+b} + B\sin\frac{\alpha x_s}{a+b} \qquad (12)$$

Thus the centroids of the gyrostatic links lie on a harmonic curve of wave-length $2\pi(a+b)/\alpha$, which may be regarded as the projection on a plane through A B, of the helical configuration of the particles in a circularly polarized wave. The period is $2\pi/\mu$, and therefore a circularly polarized wave is propagated along the chain at speed $\mu(a+b)/\alpha = V$, say. But $1-\epsilon = \cos\alpha$, so that $\epsilon = 2\sin^2\frac{1}{2}\alpha$, or, to terms of the second order inclusive, $\alpha = \sqrt{2\epsilon}$. Thus,

$$V = \frac{\mu(a+b)}{\sqrt{2\epsilon}} \qquad (13)$$

The exact value of $1/2\epsilon$ is (see (8)) [illegible]

[illegible]

$$[illegible] \qquad (14)$$

[illegible]

$$[illegible] \qquad (15)$$

[illegible] if the links be very small [illegible] multiplied by the factor $1 + Cn\mu/2P(a+b)$.

[illegible]

$$[illegible] \qquad (16)$$

nearly.

Thus we see that the velocity of propagation of the [illegible] of the flywheel remains unaltered, or vice versa. For either of these cases we have a new velocity V′ of [illegible] $2\pi/\mu = \lambda'/V'$. The difference of the velocities is

$$V - V' = [illegible] \qquad (17)$$

The more exact value of the velocity of propagation [illegible]

this case (n and μ in opposite directions) is obtained from (14), which becomes

$$V'^2 = \frac{P(a+b)}{m}\left\{1 - \frac{(\beta n + \gamma\mu)\mu}{P - \frac{b}{a}(\beta n + \gamma\mu)\mu}\right\} \quad . \quad . \quad (19)$$

Also from (14) we see that, for n and μ in the same direction, V^2 is still positive when for P is substituted $-$P, provided the numerical value of P lies between certain limits, that is the motion is then still possible under thrust. This point is not dealt with in Lord Kelvin's paper. If we examine (14) we see that if we take P as the value of the thrust, reckoned positive, it must lie between the limits $(\beta n - \gamma\mu)\mu(1 + b/a)$ and $(\beta n - \gamma\mu)\mu\, b/a$. It is assumed of course that $\beta n > \gamma\mu$.

In the case, (19), above, in which n and μ are in opposite directions (n and μ being the positive numerical values) V'^2 is positive when P is greater than $(\beta n + \gamma\mu)\mu(1 + b/a)$, and also when P is less than $(\beta n + \gamma\mu)\mu\, b/a$. When P has a value between these limits V'^2 is negative and the motion is impossible. The motion in this case is not possible at all under thrust. The limits of tension just given are, it will be seen, in a sense complementary to those of thrust in the other case.

It is important to notice that the gyrostatic chain has been supposed to lie at each instant in a plane harmonic curve having the line AB (or ZZ′, Fig. 24) as axis. It therefore does not directly represent by its motion a circularly polarized wave. For that we should have to suppose the gyrostats to lie at each instant on a helix having AB as axis, and all the gyrostats to turn at the same speed in equal circles round the axis. By a similar analysis to that given above, the wave velocity might have been found for this more general case, instead of that chosen by Lord Kelvin. We should, however, have obtained precisely equations (14) and (19) above: indeed it is not very difficult to see without further analysis that this must be the result. Hence the investigation given above illustrates circularly polarized waves precisely.

Now, returning to equation (18), imagine two chains of gyrostats in all respects the same as to lengths of links, masses, and angular momenta of flywheels, to exist side by side, each turning in steady motion with angular speed numerically μ, one about a line AB, the other about a parallel line A′B′, but in opposite directions, and having each the configuration shown above to be necessary for steady motion. The wave-lengths will be λ and λ' and the wave-velocities V and V′.

The amount of turning per unit of distance travelled is $2\pi/\lambda$ in one case and $2\pi/\lambda'$ in the other. The difference is $2\pi(1/\lambda' - 1/\lambda) = \mu(V - V')/VV'$. Using $\sqrt{P(a+b)/m}$ for both V and V′ in the denominator, we get for the difference of turning specified the value $2\pi C n\mu\, P(a+b)\lambda$.

These two waves are analogous to the oppositely turning circularly polarized waves into which a plane polarized wave received by a medium dominated by a distribution of quasi-molecular gyrostats is resolved by the medium. Half the difference just found, that is $\pi C n \mu / P(a+b)\lambda$, corresponds to the turning of the plane of polarization per unit distance travelled by these waves.

(7) *Continuous elastic medium loaded with small gyrostats.*—Consider a medium endowed with rigidity and containing a uniform distribution of quasi-molecular gyrostats, the axes of which are similarly directed. A plane wave travels along this direction, which we take as that of the axis Oz. The displacements in the wave are transverse to this direction, and at any point O are supposed to be resolved along two axes Ox, Oy at right angles to one another and to Oz.

Consider an element of length dz, at the centre of which is the point O, and let its cross-section have dimensions dx, dy. Let the distributed angular momentum (A.M.) be N per unit of volume, so that the A.M. of the element is N $dx\,dy\,dz$, and the displacements at the centre O be ξ, η in the x and y directions respectively. The element is turning with the angular speeds

$$\frac{1}{2}\frac{\partial}{\partial t}\frac{\partial \xi}{\partial z} \text{ about axis of } y, \; -\frac{1}{2}\frac{\partial}{\partial t}\frac{\partial \eta}{\partial z} \text{ about axis of } x.$$

In consequence of this turning there are rates of growth of A.M.

$$\frac{1}{2}\mathrm{N}\frac{\partial}{\partial t}\frac{\partial \xi}{\partial z}\,dx\,dy\,dz, \text{ about axis of } x,$$

$$-\frac{1}{2}\mathrm{N}\frac{\partial}{\partial t}\frac{\partial \eta}{\partial z}\,dx\,dy\,dz, \text{ about axis of } y.$$

Hence there must act on the element couples about these axes given by

$$\left.\begin{aligned} \mathrm{P}\,dx\,dy\,dz &= \frac{1}{2}\mathrm{N}\frac{\partial}{\partial t}\frac{\partial \xi}{\partial z}\,dx\,dy\,dz \\ \mathrm{Q}\,dx\,dy\,dz &= -\frac{1}{2}\mathrm{N}\frac{\partial}{\partial t}\frac{\partial \eta}{\partial z}\,dx\,dy\,dz \end{aligned}\right\} \quad . \quad . \quad (1)$$

These are due to tangential stresses, and these stresses it is easy to see must be equally distributed, for the axis of x, over the two sets of planes parallel to that axis, that is the tangential stresses must be equally of the types (YZ), (ZY); and similarly for the axis of y the tangential stresses must be equally of the two types (XZ), (ZX).

The tangential stress at the point O is thus $\frac{1}{2}$P in the direction of z, and $-\frac{1}{2}$P in the direction of y for the planes parallel to the axis of x. Similarly we get stresses $\frac{1}{2}$Q and $-\frac{1}{2}$Q for the planes parallel to the axis of y. We denote the forces in the directions of Ox and Oy by X, Y respectively.

These shearing forces vary from point to point, and clearly the body-force in the direction of Ox is for the element

$$\frac{\partial \mathrm{X}}{\partial z}\,dz\,.\,dy\,dx = \frac{1}{4}\mathrm{N}\frac{\partial}{\partial t}\frac{\partial^2 \eta}{\partial z^2}\,dx\,dy\,dz \quad . \quad . \quad (2)$$

Similarly the body-force in the direction of Oy is

$$\frac{\partial \mathrm{Y}}{\partial z}\,dz\,.\,dx\,dy = -\frac{1}{4}\mathrm{N}\frac{\partial}{\partial t}\frac{\partial^2 \xi}{\partial z^2}\,dx\,dy\,dz\,. \quad . \quad (3)$$

The resultant forces applied in the directions Ox and Oy by the shearing stresses due to the ordinary rigidity are, if μ *now denote the rigidity modulus,*

$$\mu\frac{\partial^2 \xi}{\partial z^2}\,dx\,dy\,dz, \qquad \mu\frac{\partial^2 \eta}{\partial z^2}\,dx\,dy\,dz.$$

Hence we obtain the equations of motion [illegible]

[illegible] (4)

[illegible]

It will be observed that geometrically ζ denotes the [illegible]

[illegible] (8)

we obtain a definite quadratic equation for m^2 (n is sup- [illegible] is the speed of propagation. One of these is the speed in [illegible]

[illegible] equation, which gives the speed of propagation in the positive and negative directions when the sign of the argument nt is reversed. Thus, in these two ways of [illegible] discrimination of the four roots.

From (8) we obtain by substitution in (7)

[illegible]

[illegible] Hence, if Nn be small in comparison with μ we get

[illegible]

[illegible]

[illegible] m_1 for m, on the understanding that

[illegible]

where on the right n is supposed to be [illegible]

[illegible] first with speed

[illegible]

the second with speed

[illegible]

[illegible] distance in the respective times

[illegible]

Hence in a maintained train of plane polarized waves of definite frequency $n/2\pi$ one circular motion will gain on the other, per unit distance travelled, by the angle

$$\frac{1}{4}\frac{N n^2}{\mu}\sqrt{\frac{\rho}{\mu}}$$

and the plane of polarization will turn through half this angle.

It is interesting to compare this with the turning of the plane of polarization suggested by the two chains of gyrostats described at the end of § 6. As in that discussion μ and n were used as the angular speed of the chain about the line A B and the angular speed of the flywheels respectively; while here μ denotes the rigidity of the continuous medium and n the so-called "speed" of the impressed harmonic motion, we express the two rates of turning in terms of wave-velocity and wave-length, and write L for the angular momentum of a flywheel so that $C n = L$.

The relative turning for the gyrostatic chains was found to be $2\pi C n \mu / P(a+b)\lambda$, which if $V^2 m$ be put for $P(a+b)$ becomes $2\pi L \mu / m V^2 \lambda$. But $\mu\lambda/2\pi = V$, so that $\mu = 2\pi V/\lambda$. Thus the relative turning for the chains is

$$4\pi^2 \frac{L}{m V \lambda^2}.$$

The relative turning of the two circularly polarized waves in the gyrostatic medium is $\frac{1}{4} N n^2/\mu V$, where the letters n and μ have the different meanings referred to above. But $\mu = \rho V^2$ and $n\lambda = 2\pi V$, so that $V^2 = n^2\lambda^2/4\pi^2$, and $\mu = \rho n^2 \lambda^2 / 4\pi^2$. Hence the relative turning in this case is

$$\pi^2 \frac{N}{\rho V \lambda^2}.$$

The two expressions are thus quite analogous, with the correspondence N, ρ to L, m. They differ only by a numerical factor which arises from the fact that in one case we have a chain revolving in free space, and in the other gyrostatic elements of a rigid medium moving under the control of the rigidity.

It will be seen that, in either of the gyrostatic illustrations, if the plane polarized system of vibrations be reflected back after passage in one direction, the turning in the second passage will be in the same direction as in the first, so that the total turning will be twice that for a single passage. This is the characteristic of magneto-optic rotation as distinguished from the rotation produced by a plate of quartz or a solution of sugar, where the turning in the forward passage is annulled in the backward passage. This points to the fact, already referred to above, that the rotation of the plane of polarization in the latter case is an affair of structure of the medium.

(8) *Gyrostat hung by steel wire. Axis horizontal without spin.*—Let the gyrostat be turning in azimuth so that the wire is twisting or untwisting. Let the wire have torsional rigidity τ, that is, the couple required to maintain the lower end in position, when turned round the axis of the wire through an angle ϕ from the position of equilibrium, be $\tau\phi$.

As we shall see, the plane of the flywheel will not remain vertical, and we suppose that, at the instant, the inclination of the axis to the horizontal is θ, as shown in the diagram, reckoned positive when the turning is in the counter-clock direction about the horizontal axis O A, as seen from beyond A. If ϕ be, as we assume, always small, θ will always be small also.

Now suppose the angular momentum $C n$ of the wheel to be represented by the line O B drawn from the centre O of the gyrostat, and that the lower end of the wire is turning in the azimuthal direction indicated by the curved arrow at the top of the diagram. Hence angular momentum

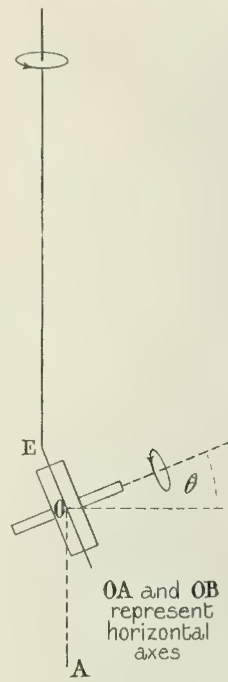


FIG. 25.

is being produced about the horizontal axis O A at rate $-C n \dot{\phi}$. The gyrostat must be tilted with the end B of the axis up, through the angle θ (exaggerated in the diagram), to give a couple for this growth of angular momentum. The moment of the couple is $M g a \theta$ if M be the whole mass of the gyrostat and a the distance of the point of attachment of the wire from the centre of gravity O. The total rate of production of angular momentum about O A is $A'\ddot{\theta} - C n \dot{\phi}$, where A′ is the moment of inertia of the gyrostat about the point of attachment E of the wire. Putting this rate equal to the moment of the couple in the positive direction, we get the equation of motion

$$A'\ddot{\theta} - C n \dot{\phi} = -M g a \theta \quad . \quad . \quad . \quad . \quad (1)$$

But in consequence of the turning at rate $\dot{\theta}$ angular momentum is being produced about the upward vertical at rate $C n \dot{\theta}$, and the total rate about that axis is $A\ddot{\phi} + C n \dot{\theta}$. Hence we get the equation

$$A\ddot{\phi} + C n \dot{\theta} = -\tau\phi \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

It is to be noted that the azimuthal motion of the tilted gyrostat will cause slight deviations of the long suspension wire from the vertical: these are here neglected.

If now we suppose θ so small, *and the period also so great*, that $\ddot{\theta}$ may be neglected, we have $C n \dot{\phi} = M g a \theta$, and

[illegible]

$$[illegible] \qquad (5)$$

[illegible]

$$[illegible] \qquad (6)$$

[illegible] a quadratic equation for the determination of k. [illegible]

[illegible] wire be made very long, the product of the roots [illegible] k^2 is still numerically great. Thus the equation has then a small root and a comparatively large one. The small root is obtained approximately from

$$- [illegible] = 0 \qquad (6)$$

[illegible]

$$[illegible] = 0 \qquad (7)$$

Neglecting the term $\tau A'$ in the expression in brackets, we obtain for the small root

$$k^2 = \frac{M [illegible]}{C^2 n^2 + M [illegible] A} \qquad (8)$$

[illegible]

$$\frac{2\pi}{k} = [illegible] \qquad (9)$$

Thus, regarding the matter from the point of view of [illegible] that the moment of inertia of the gyrostat as a torsional [illegible]

Now take the large root given by the equation

$$k^2 = \frac{C^2 n^2 + M [illegible] A}{A A'} \qquad (10)$$

The period of oscillation is

$$\frac{2\pi}{k} = 2\pi \sqrt{\frac{A}{M [illegible] + \frac{C^2 n^2}{A}}} \qquad (11)$$

[illegible] to turn about two axes [illegible] an arrangement [illegible] stat, and the other below it, and neither of [illegible] be the ring on which the gyrostat is immediately [illegible], or the axis carrying the gyrostat may be one about which the frame or case of the gyrostat is free to turn, and that [illegible] centre of gravity from the axis considered, what has been [illegible] or negative.

Let, then, the masses which turn about the respective [illegible] of gravity above (or distances from) the axes be h, h', the [illegible] angular deflections (supposed small) from the vertical be [illegible] speed of the flywheel be C, n. We get then by the process [illegible] lar momentum about the axes, fixed in the present case,

$$[illegible]$$

[illegible]

[illegible]

another, we might take them as parallel to axes of x and y drawn from an origin on the vertical through the centre of gravity for the upright position. Each turning is to be taken as positive when it is counter-clockwise to an eye looking at the apparatus towards the origin from a point on the axis of rotation at a positive distance from the origin. The axis of z may be taken downwards.]

If, taking the case of double instability without spin, we write $B = M g h$, $B' = M' g h'$, Equations (1) become

$$A \ddot{\phi} + C n \dot{\psi} - B \phi = 0, \quad A' \ddot{\psi} - C n \dot{\phi} - B' \psi = 0 \quad . \quad (2)$$

[The reader will observe that the meaning of ψ is here different from that assigned to the same symbol in the theory of a single gyrostat set forth above.]

Now let $$\phi = a e^{ikt}, \quad \psi = b e^{ikt} \quad . \quad . \quad . \quad . \quad . \quad (3)$$

where a and b are constants, which are in general complex numbers, that is are of the form $\alpha + i\beta$, $(i = \sqrt{-1})$. Thus by substitution in (2) we get

$$\left.\begin{array}{r} -(k^2 A + B) a + i k C n b = 0 \\ -i k C n a - (k^2 A' + B') b = 0 \end{array}\right\} \quad . \quad . \quad . \quad (4)$$

and therefore by elimination of a and b

$$A A' k^4 - (C^2 n^2 - A B' - A' B) k^2 + B B' = 0 \quad . \quad (5)$$

According to the supposition made above A, A′, B, B′ are all positive, and the roots of the quadratic in k^2 which we have obtained are real and positive if $(C^2 n^2 - A B' - A' B)^2 > 4 A A' B B'$.

These are the conditions of dynamical stability, for if they be fulfilled ϕ and ψ represent simple harmonic deviations from the equilibrium configuration (unstable in the present case without spin). Each deflection may have either of the two periods given by the two real roots k_1^2, k_2^2 of (5). The motion is oscillatory and therefore stable, and there are two modes of vibration, which may be taken, either separately or in combination, by the gyrostat. Moreover there are numerically equal positive and negative values of k given by each value of k^2.

Now it is clear that the four roots provide for the case in which the sign of n is reversed, that is for both $+n$ and $-n$. To settle what roots go with $+n$ and what with $-n$, we may proceed as follows. Suppose that $A = A'$ and $B = B'$, then equations (2) can be united in one by writing $\zeta = \phi + i\psi$. Thus multiplying the second of (2) by i and adding we get

$$A \ddot{\zeta} - C n i \dot{\zeta} - B \zeta = 0 \quad . \quad . \quad . \quad . \quad . \quad (6)$$

If now we put $$\zeta = K e^{ikt}$$

where K is a constant, we obtain from (6) the condition

$$k^2 - \frac{C n}{A} k + \frac{B}{A} = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

which yields $$k = \frac{1}{2} \frac{C n}{A}\left(1 \pm \sqrt{1 - 4\frac{A B}{C^2 n^2}}\right) \quad . \quad . \quad . \quad (8)$$

Thus for n positive k has two positive values, and for n negative has two negative values. The reversal of the direction of rotation reverses the signs of the roots. This will hold also when A and A′, and B and B′, are unequal, as there cannot be any change in the nature of the solution brought about by the equalization of these quantities.

It will be observed that if the spin be rapid the roots are $C n/A$ and $B/C n$ nearly. These are the angular speeds of possible circular motions, and agree with the results obtained above for the steady motion of a top.

The roots of the quadratic (5) are given by

$$k^2 = \frac{1}{2} f\left(1 \pm \sqrt{1 - 4\frac{g}{f^2}}\right) \quad . \quad . \quad . \quad . \quad (9)$$

where $f = (C^2 n^2 - A B' - A' B)/A A'$, $g = B B'/A A'$. This gives two positive values of k and two negative values, provided g is positive. It will be observed that if B and B′ have not the same sign g is negative, and (9) gives two real roots (equal with opposite signs) and two imaginary roots. We have just seen that the two positive values of k apply to the case of n positive. Now recurring to the case of $A = A'$, $B = B'$, we should then have been able to realize the solution very simply, by writing

$$\zeta = \phi + i\psi = (\alpha_1 + i\beta_1) e^{i k_1 t} + (\alpha_2 + i\beta_2) e^{i k_2 t} \,. \quad (10)$$

where α_1, β_1, α_2, β_2 are supposed all positive. We should have had

$$\begin{aligned} \zeta = {} & \alpha_1 \cos k_1 t - \beta_1 \sin k_1 t + \alpha_2 \cos k_2 t - \beta_2 \sin k_2 t \\ & + i(\alpha_1 \sin k_1 t + \beta_1 \cos k_1 t + \alpha_2 \sin k_2 t + \beta_2 \cos k_2 t) \quad (11) \end{aligned}$$

and therefore should have obtained the real values of ϕ and ψ by equating ϕ to the first line on the right of this equation, and $i\psi$ to the second line. But if we compare (4) with the equations we should have if $A = A'$ and $B = B'$, we see that we must have for positive n

$$\left.\begin{array}{l} \phi = \alpha_1 \cos k_1 t - \beta_1 \sin k_1 t + \alpha_2 \cos k_2 t - \beta_2 \sin k_2 t \\ \psi = \rho_1 (\alpha_1 \sin k_1 t + \beta_1 \cos k_1 t) + \rho_2 (\alpha_2 \sin k_2 t + \beta_2 \cos k_2 t) \end{array}\right\} (12)$$

where $\rho = \sqrt{(k^2 A + B)/(k^2 A' + B')} = i b/a$, and ρ_1, ρ_2 are the positive values of ρ for k_1 and k_2.

If we put $-i$ in the place of $+i$ in (10), (12) becomes

$$\left.\begin{array}{l} \phi = \alpha_1 \cos k_1 t + \beta_1 \sin k_1 t + \alpha_2 \cos k_2 t + \beta_2 \sin k_2 t \\ \psi = -\rho_1(\alpha_1 \sin k_1 t - \beta_1 \cos k_1 t) - \rho_2(\alpha_2 \sin k_2 t - \beta_2 \cos k_2 t) \end{array}\right\} (13)$$

Thus we have simply changed the signs of the arguments. In (12) and (13) k_1 and k_2 are to be taken positive, as the effect of changing from the positive to the negative roots has been taken account of in the signs of the coefficients in (13). These changes correspond to a reversal of the spin n, as may be seen from the values of the roots of the biquadratic (5) as given in (8). It will be seen that each pair of terms of (12), made up of the first term in ϕ and the first term of ψ, or of the second, third, or fourth term in each expression, would if ρ were unity give a circular motion in the positive direction, and that similarly the corresponding pairs of terms in (13) would represent circular motions in the opposite direction.

It is now obvious that there are two modes of motion for each direction of spin provided the product B, B′ is positive. By the spin the two instabilities which existed without spin have been replaced by stabilities. If B, B′ be negative there is only one possible mode of motion for each direction of spin, and complete stability has not been attained.

The [illegible] [illegible] compass.

[illegible] positive. The equations are now

$$A\ddot{\xi} + [illegible] \qquad (1)$$

If we had A = A′, B = B′, we should write the single equation

$$A\ddot{\zeta} - Cn i\dot{\zeta} + B\zeta = 0 \qquad (2)$$

where [illegible]

[illegible]

so that [illegible] (3)

[illegible] reversed in sign. Thus for a given direction of spin there are two roots [illegible] and for the reversed spin there are the two roots [illegible].

We find in the same manner as before

$$[illegible] \qquad (4)$$

Here [illegible] are taken as the positive values of

$$\sqrt{(k^2 A - B)(k^2 A' - B')}$$

for the respective values of k.

If we change the direction of spin we get

$$[illegible] \qquad (5)$$

If ρ were unity the first pair of terms, or the second pair of terms [illegible] in (4) would give a circular motion in the positive direction, and either pair of terms in k_2 a circular motion in the negative direction. These circular motions are reversed in (5). There is thus the remarkable difference between this double [illegible] case and the former, that now circular motions in opposite directions can be superimposed. The periods of these two motions are $2\pi/k_1$, $2\pi/k_2$. The greater angular speed k_1, which for A = A′, B = B′ is C n/A nearly, is round in the direction of [illegible] [illegible] That is as seen from below in both cases. Refer to the description of the gyrostatic pendulum in the lecture.

(11) [illegible] Royal Institution Lecture, delivered in 1898, that the motion now explicitly stated in [illegible] the Zeeman effect. An electron moving in a circular [illegible]

[illegible]

$$[illegible]$$

or [illegible]

where [illegible]

These are exactly the equations of motion of an electron

Fig. 20

[illegible] magnetic field directed upward through the paper (Fig. 20).

[illegible] electron from O. The convection currents are here $e\dot{x}$, [illegible] μeH/m. The other outward component forces are then [illegible]

$$[illegible]$$

Assuming that $z = Ke^{ikt}$, (K = a constant), we obtain

$$[illegible]$$

Again by reversing the sign of k we obtain

$$k^2 - \kappa + \gamma k = 0,$$

so that we have $$k^2 = \kappa \pm \gamma k,$$

and if γ is small the numerical value of k is given by

$$k = \sqrt{\kappa} \pm \tfrac{1}{2}\gamma.$$

The frequency of the original vibration was $\sqrt{\kappa}/2\pi$: the imposition of the magnetic field has produced two new frequencies $(\sqrt{\kappa} + \frac{1}{2}\gamma)/2\pi$, $(\sqrt{\kappa} - \frac{1}{2}\gamma)/2\pi$, one higher the other lower than the original frequency. The former frequency is that of electrons describing orbits in the direction shown in Fig. 26; the latter frequency is that of electrons moving in the opposite direction. Electrons moving along the line of the force H are not affected; hence the spectrum is modified by the production of two satellitic lines, one above the ordinary line, the other below it, in the spectrum.

The structure of the electron and its gyrostatic effects are further questions not entered into here.

Professor Thompson.

Professor SILVANUS P. THOMPSON: I ask you to give a most hearty vote of thanks to Professor Andrew Gray, the pupil, the assistant, the collaborator, and the successor in the Chair of Natural Philosophy at Glasgow University, of Lord Kelvin, him whom we honour for the sixth time by this Kelvin Lecture. In all the Kelvin Lectures which have succeeded the first biographical one, the successive lecturers have each taken some particular aspect of Kelvin's work, and have illustrated it and elaborated it for us. To-night we have had shown to us—and when we read the Lecture we shall have the opportunity of making ourselves better acquainted with it—one department of Kelvin's work with which perhaps most of us are less familiar than we are with other matters more directly connected with electricity and magnetism and their applications. The particular side of Kelvin's activities which Professor Gray has illustrated to us is truly characteristic of the man; perhaps more characteristic than some of the other aspects which have been expounded to us in former years. When Lord Kelvin was only fifteen, a young student in Glasgow, he wrote a very remarkable essay which has never been published, but exists in manuscript, and which was added to by him at three successive periods of his life, an essay which was awarded the Gold Medal of the University, on "The Figure of the Earth." I suppose in the thirties or forties the mathematical treatment of the figure of the earth, why it presented the shape of a peculiar kind of ellipsoid, and how that shape can be explained dynamically, were amongst the burning problems of mathematical physics. I once attempted to read Archdeacon Pratt's "Figure of the Earth," and found it very stiff mathematics and gave it up. Lord Kelvin's early essay on "The Figure of the Earth" haunted him through life. He was continually recurring in one way or another to the origin of the earth as it is, to its geological history, and to dynamical explanations of how the earth came to be what it is. We know how he thought about the age of the earth, its heat, its magnetism, and other properties of it. The dynamics of the figure of the earth was, as I have said, a subject that haunted him. We have had described to us by Professor Gray these various early parts of Kelvin's work when he was trying to regard the earth, not as a solid ellipsoid, but as a hollow one containing liquid. It was a little chapter in the history of Kelvin's mental development. He was continually at this problem of what would happen to a spinning body under various conditions; and in particular this question of what would happen to a spinning body if it were given a certain geometrical form, and if certain properties—liquid, rigid, or elastic—were assumed for its interior contents. He was extraordinarily fond of experiments with spinning eggs. There was one which I think Professor Gray did not mention, and which I remember seeing Kelvin perform at least three times, to test the difference between a boiled egg and an unboiled one, by which one can ascertain at once whether an egg is liquid or solid inside. It was this:—Place an egg on a smooth table, and, holding it between the hands, give it a spin on its side. Then stop it for a moment by laying one finger on it. Then lift the finger off; if it is a solid egg, hard boiled, it remains stationary. If it is a liquid egg, the moment one takes one's finger off, the egg begins gently to rotate again because the liquid has not ceased running round inside. He was exceedingly fond of this kind of curious experiment, as who would not be if his mind were trained to take a delight in geometrical and dynamical problems? Consider the perverse behaviour of these gyrostats which when we try to push them on one side turn up or turn down; or which when we carry them round turn head over heels; or which in some cases, if we try to push them over when they are standing upright, turn over the other way and tend to recoil against us. The perversities of these gyrostats are an endless source of thought to those who would master the dynamics of rotation. It is perfectly true that Lord Kelvin himself, in the attempt to explain on gyrostatic principles other phenomena such as electricity, magnetism, the polarization of light, etc., advanced propositions and problems which, by the light of further knowledge, he did not see his way further to maintain. We know how he gave up the vortex theory of atoms when the logical issues of the problem appeared to outrun the theory that he had reached. We have heard from Professor Gray to-night how Kelvin gave up the explanation which he had advanced in earlier life of the rotatory polarization of light; but he never abandoned, and I think he never would have abandoned, one most valuable suggestion that he made, namely, the doctrine of hidden mechanism. That doctrine is, that we may have a model, so to speak, of an atom, or group of atoms, or a molecule, or a system—a model, the mechanism of which is concealed, like the spinning body of the gyrostat inside a case, but which nevertheless is a true dynamical model. We may have a thing which is indistinguishable as to whether it is a gyrostat, or a chain of gyrostats, or a spiral spring, or a coach spring, which externally may be identical in behaviour, but of which the hidden mechanism may be very different. All his life Kelvin was seeking for that hidden mechanism which he firmly believed to exist, and which he considered would some day give us a complete dynamical theory of the atom and the molecule; for he hoped unquestionably to become, so to speak, the Newton of the atom, who would dynami-

[illegible] I remember well that British Association Address of his in 1876, when he came back from America. He was full of two things: the invention by Graham Bell of the telephone transmitting speech by magneto-electric induction; and this question of the rotation of the earth, which he had discussed with Simon Newcomb in Joseph Henry's drawing-room. The way in which the problem of the rotation of the earth cropped up again and again in the middle of other matters was really amusing. Lord Kelvin's great breadth of thought was well illustrated by the curious interpenetration of these diverse interests. We must not think of him as a man who merely applied science to the practical problems of the compass, of the [illegible] the measurements of electricity and magnetism. He was supremely great in all these things. He had a mind which explored the minute and which [illegible] the infinite. The problems of the cosmos and of the atom loomed equally large in his mind with the practical problems of the applications of science. We are all very grateful to Professor Andrew Gray for the exposition that he has given us of these matters in which he personally helped Lord Kelvin. We shall be delighted at the conclusion of the meeting to see the further applications which he has continued to make with his son.

[illegible] done, the inner meaning of that work. Lord Kelvin all [illegible] has shown to us to-night. We owe a debt to Professor Gray [illegible] Lord Kelvin's work.

Professor A. Gray: [illegible] Thompson said, and the fact will, I think, be found to be illustrated throughout the Lecture, as printed, that Lord Kelvin [illegible] supposed the ether to possess, and also for illustrating the [illegible] I am very much indebted to my son, Dr. J. G. Gray, for coming here to-night to help me with my experiments and for enabling me to use in these the beautiful new [illegible] invented.

SEPARATION OF THE NO-LOAD STRAY LOSSES IN A CONTINUOUS-CURRENT MACHINE BY STROBOSCOPIC RUNNING-DOWN METHODS.

By Professor DAVID ROBERTSON, D.Sc., Member.

(*Paper received 29 June, 1914.*)

CONTENTS.

RUNNING-DOWN TEST.

The method of separating the no-load loss into its various components by means of running-down, or retardation, tests seem to have been first suggested by Ashworth (4)* in a letter to the *Electrician.* It is now fairly well known, but its application to the smaller class of machines is somewhat limited by the difficulties that arise from the quickness with which these machines come to rest. It is the object of this paper to show how these difficulties can be partly overcome.

A list of the chief papers on the subject is given in an appendix, but particular attention may be called to those of Hay (9), Sumpner (11), and Smith (17). The last mentioned gives a particularly good account both of the variations of the running-down method and also of the other ways in which the separation has been accomplished.

The general principle of the test may be explained briefly thus: While running steadily as a motor at the desired speed and excitation, the power absorbed by the armature of the machine to be tested is measured by a suitable ammeter and voltmeter, or by a wattmeter. If available, the wattmeter is to be preferred as it reduces the error caused by the inevitable momentary changes of voltage which occur on a commercial supply system. After allowing for the copper losses, the stray power at that speed, consisting of friction, eddy currents, and hysteresis, is then known and also the corresponding retarding torque.

On breaking the armature circuit, while maintaining the field current constant, the machine gradually slows down under the action of a retarding torque which, at the given speed, may be assumed to be the same as that just determined. Now, the deceleration at any instant is proportional to the torque acting at that instant, and so a comparison of the decelerations at different speeds shows how the stray-loss torque varies with the speed.

If the running-down test be repeated with the field circuit broken as well as the armature circuit, the frictional torques alone will act, and a comparison of the deceleration at any speed under this condition with that obtained before will enable the total resisting torque to be divided into two parts, due respectively to the friction and to the magnetic losses. A determination of the speed-time curve under these two conditions will thus show us how the frictional and magnetic torques separately vary with the speed. Following Mordey, Kapp,* and others, we can deduce the separate values of the eddy-current and hysteresis losses from the latter variation.

With constant flux, the electromotive forces causing eddy currents are proportional to the speed, and so these currents will also be proportional to the speed so long as the frequency is low enough to make negligible the effects of the inductance of the eddy-current paths. In that case, their torque must be proportional to the speed, and the power which they consume to its square. At very small speeds there are no appreciable eddy currents, and so the magnetic torque at zero speed is due entirely to hysteresis.

For a constant magnetic cycle, the energy converted into heat by hysteresis is the same whether the cycle be performed quickly or slowly. Hence, with a constant flux the energy absorbed per revolution by hysteresis is the same at all speeds. In other words, the hysteresis torque is constant and equal to the magnetic torque at zero speed. Hence it can be found by producing the magnetic torque-speed line back to zero speed.

The eddy-current torque at any speed is obtained by subtracting the constant hysteresis torque from the total magnetic torque at that speed.

It has often been assumed (*e.g.* Smith does so, and many of the earlier writers) that the bearing friction and windage may be separated in the same way, but it is now known that the bearing friction varies with the speed and that the mathematical law of its variation is not sufficiently definite to allow of a division in that manner. The windage can only be separated with certainty from the bearing friction by comparing the resistance under ordinary conditions with that in a vacuum, as has been done by Thornton.†

If the gear allows the brushes to be quickly lifted after switching off, brush friction can be separated by making an additional running-down test with the field off. If not, an auxiliary motor would be necessary to get the machine

* The numbers in brackets after names refer to the bibliography at the end.

* G. KAPP. Separation of the Foucault and hysteresis losses. *Electrician*, vol. 26, p. 699, 1891.

† W. M. THORNTON. Change of energy losses with speed in continuous-current machines. *Journal I.E.E.*, vol. 50, p. 492, 1913.

[illegible]

[illegible]

[illegible] of that for full excitation and can be neglected in comparison with the friction.

The brushes must be set exactly at the neutral point; otherwise there will be short-circuit currents under the brushes the effect of which is included with the eddy-current losses, as will also the power used by the voltmeter if the latter is not disconnected during the running-down tests.

If a complete running-down curve has been obtained, the retardation at any point is determined by drawing the tangent there. Seeing that the scale is determined by the steady-running test, it is very necessary that the tangent to the "field on" curve at that speed should be especially carefully drawn. Since the tangent at any intermediate point can be drawn with greater accuracy than that at the end point of the curve, it is desirable that the running-down test should begin at a higher speed than that at which the steady-running measurements were made. At the same time it must be remembered that the friction when the machine is steadily running at any speed is different from that on quickly passing the same speed after running at a higher one, owing to the difference in the temperature and oiliness of the bearings at different steady speeds.

Four-point Running-down Method.

If we can be certain that the eddy-current line is straight in the torque-speed curve, observations at two speeds only are sufficient to separate the two parts of the magnetic torque. This is conveniently carried out by measuring the time taken under each condition (field off and field on) for a known drop of speed having the required speed as its mean. The upper speed should be that used for the steady-running measurements, and the other should be half of it. At half speed the hysteresis torque is the same as at full speed, but the eddy-current torque is only half as great; consequently, the difference between the magnetic torques at the two speeds is equal to the eddy-current torque at the lower speed or half that at the upper. This method may be called the Four-point Method.

[illegible]

[illegible]

Measurement of Retardation.

[illegible] proportional to the rate of change of speed of the dynamo. Difficulties occur in getting an instrument at the same time sufficiently sensitive, sufficiently quick, and sufficiently dead-beat, and the method is also open to the objection that it puts an unknown load, which may not be negligible, on the machine.

Young also gives another method, in which the auxiliary dynamo is connected to the primary of a transformer of which the magnetic circuit has an air-gap long enough to make the reluctance sensibly constant. The electromotive force in the secondary winding, which is measured by a suitable voltmeter, galvanometer, or oscillograph, is proportional to the rate of change of flux, and therefore of current and speed.

In most cases, however, retardation will not be measured directly but will be inferred from simultaneous measurements of time and speed. We may either measure the time taken for a given drop of speed, or the drop of speed in a given interval of time, as may best suit the apparatus at our disposal.

Measurement of Speed.

The principal methods that have been employed for the measurement of speed may be summarized as follows:—

(a) A tachometer or speed counter.—In addition to the unknown load which it adds, a tachometer does not, as a rule, give the exact instant of passing a given speed very sharply. When a hand instrument is employed, the end thrust on the shaft when using it may also change appreciably the losses being determined. It should not be used for machines of less than several kilowatts.

(b) A voltmeter connected to the brushes of the machine.—The chief objection to this method is that the residual magnetism has to be depended upon for the "field off" readings, which introduces difficulties as to the relative values of the speed scales for the two tests. The resistance electromotive forces of the armature and brushes with the varying armature current have to be allowed for in calibrating the voltmeter as a speed-meter, and these are considerable, especially with low-voltage machines, owing to the fact that the contact voltage does not follow Ohm's

law. This, and the variations of brush contact resistance, may cause considerable errors when running on the low-voltage scale required for the "field off" test.

The load applied by the voltmeter will be somewhere about one watt per 100 volts at the top of the scale. Even in a 5 kw. machine for 500 volts it may thus amount to several per cent of the eddy-current loss, with which it would be included in the analysis. It is, however, a known load and can be accurately allowed for.

By using a recording voltmeter, ondograph, or oscillograph, this method can be made to trace out the speed-time curve directly, but such instruments of suitable range are not often available.

(*c*) *A voltmeter connected to an auxiliary dynamo coupled to the machine under test.*—This obviates the chief objection to the use of the voltmeter for the measurement of speed, but it adds a much greater load and one that cannot be so accurately allowed for.

(*d*) *A voltmeter connected so as to measure the difference between the armature and line voltages.* By this method the drop of speed is measured and a larger scale may be employed for the initial part of the curve, which is the most important. It cannot be applied to the "field off" test, but it has been used by Sumper (11) in a method involving acceleration and retardation curves with the same armature current.

(*e*) *A frequency meter connected to a small alternator coupled to the machine under test.*—This method has no advantages over (*c*) and is open to the same objections.

(*f*) *Stroboscopic tuning fork.*—This is by far the best method, as it indicates exactly the moment of passing a speed by the reversal of the apparent motion of a pattern drawn on a card attached to the motor, and because it does not add the slightest load to the motor or interfere with it in any way. Its accuracy is greater than that of any other speed indicator, and the accuracy is the same for high and for low speeds; it has a practically indefinite speed range. The stroboscopic tuning fork is not an expensive piece of apparatus, and it is robust and permanent. Such minor repairs as may occasionally be required can be done on the spot without altering the calibration of the instrument.

The method has been strongly advocated by Drysdale (1). The present author, who can speak of its advantages after 12 years' use, has recently described the stroboscopic methods in much detail (3); but it may be convenient to repeat here the essential points regarding this particular purpose.

The Stroboscopic Tuning Fork.

A tuning fork of large size, usually electrically maintained, is arranged so as periodically to admit light to the eye. Fig. 1 shows the type of fork employed in the author's laboratory. It is driven by two storage cells and can be started by gradually turning the screw until the contacts touch, and stopped by screwing them away from one another. The amplitude can be adjusted by the same screw; the standard amplitude is that at which the apparent thickness at the tip is double the actual thickness, this being easily recognized by the disappearance of the apparent solid centre of the vibrating prong.

One edge of the prong may be used as a shutter, but it is better to attach two light aluminium wings which open and close the path of the light as they vibrate. The fork must of course be standardized with these wings in place. Two methods may be distinguished, "edge vision" and "slit vision." In the former, the path is normally closed,

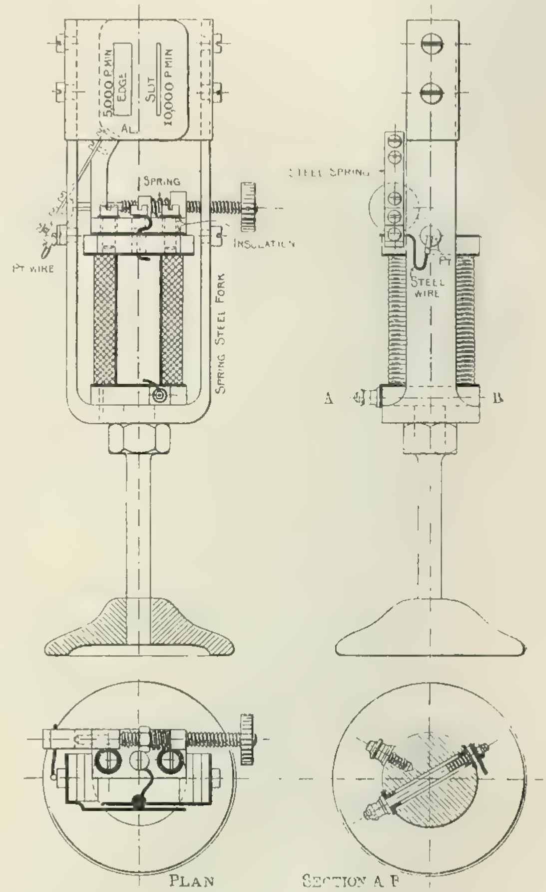


FIG. 1.—Robertson Stroboscopic Tuning Fork for Speed Measurements.*

but is opened when the displacement is great enough in one direction. For the latter method, slits in the two wings are exactly opposite to one another when the prongs are at

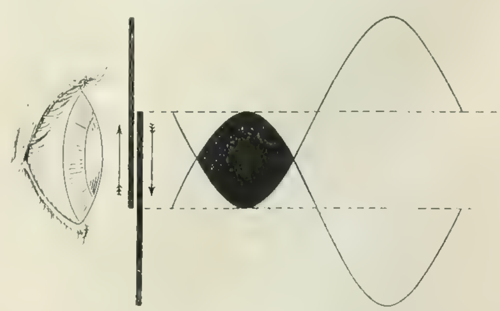


FIG. 2.—Edge Vision with Vibrating Shutter.
(Amplitude = overlap.)

rest, but the path is closed when the displacement of each prong is half the slit width. In Figs. 2 and 3 the sine curves show the displacement of the edges of the slits, and

* This, and Figs. 2, 3, 5, 6, 7, 8, and 9 are taken from the author's paper read before the Institution of Engineers and Shipbuilders (3).

the black spaces denote the duration and extent of the opening. It will be seen that edge vision gives an opening at each extreme of positive displacement, while slit vision gives one each time the prongs pass their equilibrium position. Consequently, with edge vision the frequency of the glimpses is the same as that of the fork, but with slit vision it is twice as much. It is convenient to arrange the wings so that either frequency may be employed, but slit vision is generally to be preferred as it gives better images owing to the sharper cutoff. The frequency of the fork shown in Fig. 2 is fifty cycles per second, giving glimpse frequencies of 3,000 and 6,000 per minute.

Fig. 3.—Slit Vision with Vibrating Shutter.
(Amplitude = slit width.)

This is a very convenient frequency, but 6,000 and 12,000 per minute would be better, as it would give more speeds at exact hundreds. These forks can be relied on for constancy to about one part in 1,000, and their temperature variation is almost negligible, being only about one part in 5,000 for each degree Centigrade.

Stroboscopic Vision.

The vibrating shutter may be held close to the eye so as to permit intermittent glimpses of a pattern marked on some revolving part of the machine under test. For constant-speed work this is very satisfactory, but for the

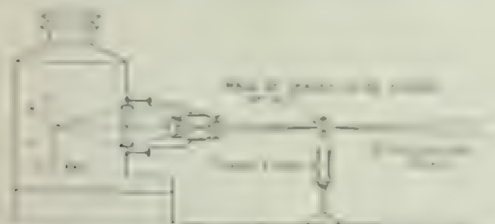
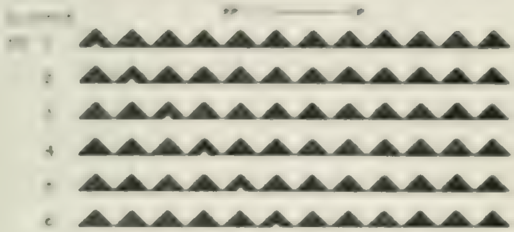


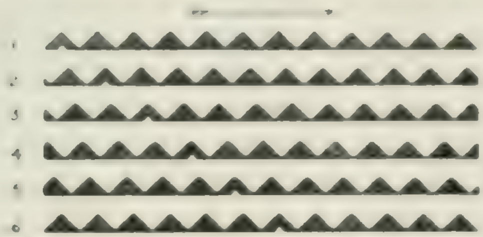
Fig. 4.—Arrangement for obtaining Stroboscopic Beam.

running-down test it is much better to project the light from an arc lamp through the slit on to the stroboscopic disc. The changes of speed can then be seen from any point and can be followed by any number of persons at once. Fig. 4 shows how this can be conveniently done with an ordinary projection lantern.

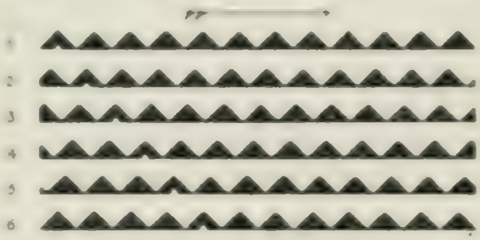
Primary speed.—The pattern consists of a number of equally spaced spots or marks on the pulley or on a card fixed to the shaft. Let the speed be such that during the interval between the centres of successive glimpses the spots move exactly one pitch forward (see Fig. 5). Each spot will then be in the position which was occupied at the previous glimpse by the one ahead, but, owing to the persistence of the impression on the eye and to the fact that all the spots are similar, it will seem as if no motion had taken place. The result is that the whole set can be seen, although they are actually in rapid motion, and they appear to be stationary. This may be termed the "primary speed," to distinguish it from the other synchronous speeds referred to below. The motion of the spots during the



Spot Frequency equal to Glimpse Frequency.



Spot Frequency greater than Glimpse Frequency.



Spot Frequency just under Glimpse Frequency.

Fig. 5.—Actions near Primary Speed.

(The arrows indicate direction of motion.)

time the glimpse lasts causes a certain amount of blurring, tail and loss of distinctness of the images, but this can be reduced as much as desired at the expense of brightness by cutting down the duration of the opening.

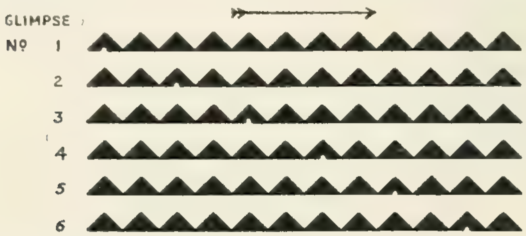
Should the speed be a little over synchronism, the spots will reach a little further than the next place by the second glimpse, but the same causes which formerly made them appear to be stationary will now give the eye the impression that each has only moved a distance equal to the excess of their motion over their pitch. The result is that the whole set is seen moving slowly forward with a velocity equal to the excess of their speed above synchronism. In the same way, should the speed be a

trifle low, the pattern will appear to be moving backwards with a speed equal to the defect from synchronism.

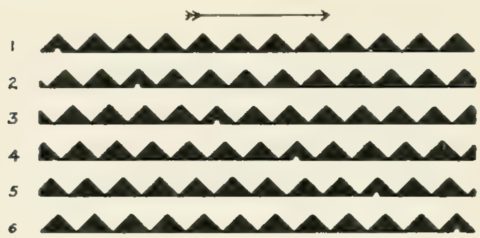
From Fig. 5 it can easily be seen that in either case the fraction of the pitch which is gained or lost at each glimpse is the same as the fractional error of the speed, and that the slip, measured in spots per unit time, is the same for the same proportional error of speed, whether high speeds and few spots or low speeds and many spots are being dealt with. It is proportional to the glimpse frequency.

Multiple speeds.—When running at twice the primary speed, the motion during the glimpse period is twice the pitch, and at the second glimpse each mark is exactly at the place formerly occupied by the second one ahead (see Fig. 6). They consequently appear to be steady, but the definition is not so good as at the primary speed because the movement during the time of vision is twice as great. In the same way as before, the pattern seems to move forward when the speed is too high, and backward when it is too low. The slip frequency is twice as great as before, and corresponds to a glimpse frequency of twice the actual value.

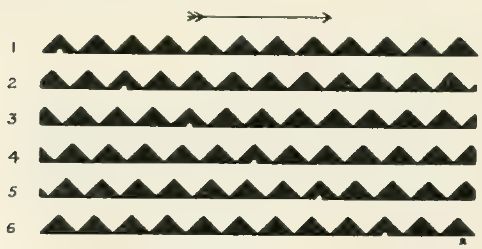
In a similar manner we may get stationary patterns at 3, 4, 5, etc., times the primary speed, having 3, 4, 5, etc., times as much drawing out, and having the speed errors magnified 3, 4, 5, etc., times, corresponding to glimpse frequencies 3, 4, 5, etc., times the actual glimpse frequency. The upper limit of the order of the multiple which can be observed is set by the increased drawing out of the images, and by the difficulty of finding them owing to the small range of speed over which their magnified slip is low enough to allow them to be visible. Unless the duration of the glimpse be a very small fraction of the glimpse period, the images get rapidly fainter as the order is raised.



Spot Frequency equal to Twice Glimpse Frequency.

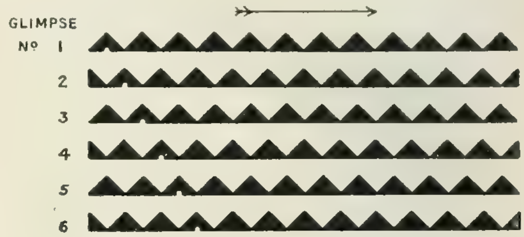


Spot Frequency just over Twice Glimpse Frequency.

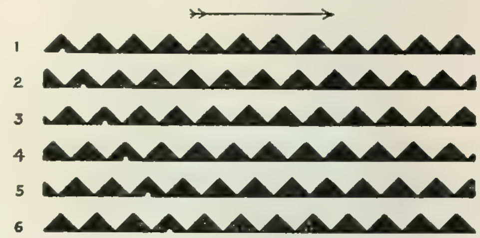


Spot Frequency just under Twice Glimpse Frequency.

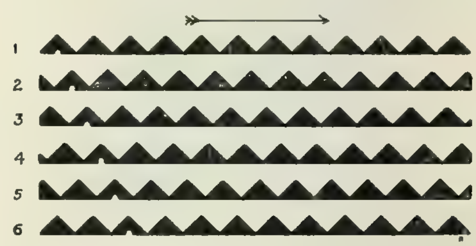
FIG. 6.—Actions near Twice Primary Speed.
(One mark has been notched to show the actual motion.)



Spot Frequency equal to Half Glimpse Frequency.



Spot Frequency just over Half Glimpse Frequency.



Spot Frequency just under Half Glimpse Frequency.

FIG. 7.—Actions near Half Primary Speed.
(One mark has been notched to show the actual motion.)

Multiples of the primary speed cannot be distinguished from one another merely by their appearance. Unless the speed is known approximately, for example from the appearance of other patterns on the same shaft, they must be counted as the speed is raised, or as the machine is shut down. Successive multiple speeds of the same pattern are in the ratio 1 : 2 : 3, etc., and so they give an even speed scale.

Submultiple speeds.—Stationary patterns are also observed when the speed is a submultiple of the primary speed. Thus at half primary speed, the spots move only half a

[illegible]

Fig. 8.—Overlapping of Gothic Spots at Submultiples of Primary Speed.

When the speed is not right the apparent motion of the spots is the same as if their actual number were increased to that appearing on the pattern, which is that number for which the synchronous speed would be the primary one. For the same proportional error from any of these speeds the same slip of the spots is obtained as with the primary speed. As may be seen from Fig. 8 the submultiple speeds can easily be distinguished from one another by counting the number of rings of peaks in the pattern, provided the spots have a suitable shape. The best form is the Gothic tooth form shown in this diagram and in Fig. 9.

Less distinct patterns are formed at multiples of these speeds exactly as they were formed at multiples of the primary speed. Up to twice primary speed, nearly 50 patterns can be detected on a single ring of spots with [illegible] sharpness of cut-off given by the tuning fork. With a [illegible] but it then becomes difficult to tell one from another unless the speed be known. About 10 patterns are strong

[illegible]

Fig. 9.—Stroboscopic Disc for Running-down Tests.

[illegible] speeds only. At quarter primary speed for the 16 ring, we have primary speed for the 64 one. Below that point, [illegible] primary speed, with the addition of 4/3 for the 64 ring only. The appendix explains fully how the results are worked up and also gives the values for actual tests.

[illegible]

[illegible] carried out with its [illegible] time. For this purpose [illegible] speed. The latter [illegible]

now sold at quite a low price for use in elementary physical work. By pasting on the glass a rim of paper on which the position of the hand is marked as each speed is passed, the actual times can be read off at leisure after the test is made. The curves given in the appendix were obtained in this way. Smith (17) uses a similar dodge in applying the voltmeter method.

Sumpner (11) finds the time taken for the speed to fall from one value to another by counting the beats of an ordinary watch; he states that with practice a greater accuracy can be obtained in this way than by employing a stop-watch. To carry out the 4-point test satisfactorily it is necessary to be able to measure an interval of time as short as one second with fair accuracy, and this cannot be done with an ordinary stop-watch. For this purpose, the author has devised an electrical chronometer reading to 0·01 second, which is described in the next section.

Electrical Chronometer.

A very successful and inexpensive electrical chronometer has been made by altering a Westinghouse ampere-hour meter of the shunted commutator type (Type 0). A scale of 100 divisions was marked round the periphery of the disc, and a scale of disc revolutions put on the second spindle. The rest of the gearing and the shunt were removed. A series resistance was added such as to make the speed one revolution per second when run on a 4-volt accumulator, and a pressel lighting switch in the circuit allows the instrument to be started and stopped much like an ordinary stop-watch.

With a meter of this type, provided the friction be negligible, the extra rotation made after switching off the current exactly compensates for the deficiency while getting up speed.* There is probably a small error due to the variation of the torque with the phase of commutation, but with a 3-part commutator, as in this meter, it is not likely to be great. The rate of the instrument depends on the voltage of the battery, but for the present purpose only relative values are necessary. If the battery is not too small and is in the right state of charge (neither freshly charged nor nearly discharged) any change during the course of an experiment will be negligible, seeing that the chronometer takes only about ¼ ampere. Where single intervals of time are to be measured, as distinct from obtaining a series for a whole running-down curve, this instrument is much more convenient than a recording drum, although perhaps less accurate, and with its aid a number of repetitions of the test can be made in quite a short time.

Another instrument is at present being constructed in which a rotating spindle is synchronized from the same fork that gives the speed. A clutch enables a counting train to be thrown into or out of gear, and the time for which it was "in" is recorded by a series of dials.

In conclusion, the author wishes to express his thanks to three of his students—Messrs. Rose, Sainsbury, and Smale—for carrying out the experiments recorded in Appendixes I and II, and to the Governors of the Merchant Venturers' Technical College, Bristol, for the necessary apparatus, etc.

* D. Robertson. Electrical meters on variable loads. *Journal I.E.E.*, vol. 49, p. 492, 1912.

APPENDIX I.

Analysis of the No-load Losses of a Continuous-current Machine by the Running-down Method.

Apparatus in addition to the machine to be tested.

Switches, regulators, and instruments in accordance with the diagram.

Stroboscopic tuning fork, battery, projection lantern, and standard stroboscopic disc.

Clock, with large seconds hand, having a paper circle pasted on the glass.

Precautions.

(1) Before starting, check all the connections very carefully. Also see that the brushes are at the neutral point and that any auxiliary brushes are lifted.

(2) Should any deviations be made from the standard diagram, see that they are such that the current taken by the field-discharge resistance does not pass through the hold-on coil, the field regulator, or any instruments of which the readings are required. Also that the connection between the field coils and this resistance cannot be broken by any of the switches, including the starting switch.

(3) As the starter will not fly back automatically, it is essential to put it to the "off" position immediately after switching off, and to make sure it is there before switching on again.

(4) The wattmeter current-coil must be kept short-circuited and the ammeter on the high-range scale except during the final adjustment of the speed for the steady-running tests. On no account may all the wattmeter plugs be out at once.

(5) Do not forget to break the volt-coil circuits before making the running-down tests.

(6) Avoid letting the machine stand between readings, but keep it at the speed n_1 during as much of the time as possible.

(7) See that the main switch is pulled off when the experiment is complete.

Experiment.

(1) For some time beforehand, run the machine as a motor at the speed n_1 and excitation x at which it is desired to test it.

(2) When ready to begin, put the wattmeter and low-range ammeter into circuit, get the speed and field current exactly right and read all the instruments. The supply voltage should be high enough to allow a few steps of the starting resistance to be left in circuit at this stage to allow for operation (6).

(3) Quickly reduce the speed, without altering the field current, to the next synchronous value n_2, read all the instruments and run up to n_1, as soon as possible afterwards.

(4) Repeat (2) and (3) several times if necessary, to see if the conditions are steady.

(5) Break the circuits of the voltmeter and of the wattmeter volt-coil, plug up the wattmeter, and put the ammeter on the high range.

(6) [illegible] switch off both the armature and field currents by the double-pole switch.

(7) [illegible] signal.

(8) A second observer should watch the [illegible] [illegible] patterns should be used and [illegible] should be omitted when the [illegible] is too rapid.

[illegible]	[illegible]	[illegible]
2	[illegible]	12, 13, 14, 15, 16
3/2	2	12, 13, 14, 15, 16
[illegible]	1	12, 13, 14, 15, 16
	[illegible] patterns here with 4 peaks	
[illegible]	3	12, 13, 14, 15, 16
1/2	2	12, 13, 14, 15, 16
[illegible]	3	12, 13, 14, 15, 16
[illegible]	4	12, 13, 14, 15, 16
[illegible]	1	64
[illegible]	4	64
2/3	3	64
1/2	2	64
1/3	3	64
1/4	4	64
Stop	(Signal "Top")	

(The brackets indicate that the last of one group coincides with the first of the next.)

(9) A third observer should follow the [illegible] different minutes if the time exceeds 60 seconds. Note that the first signal corresponds to the speed n_1 and not to the operation of the switch.

(10) The times corresponding to the various marks should [illegible] that the "tippee" marks fall into their proper place in the table. Rub all the marks off the paper ready for the next test.

(11) Repeat (6–10) until sufficient practice has been obtained to get reliable results. Number the runs consecutively in the table, including those mentioned below.

(12) Repeat (6–11) seeing that the excitation is exactly right but using the single-pole switch so as to stop the armature current but leave the field on. It will probably be necessary to omit some of the speeds.

(13) Repeat the running-down test (6–11) with the field off.

(14) Replace the volt connections and repeat the steady readings, (2–4).

[illegible]

(1) [illegible]

(2) [illegible]

(3) [illegible]

(4) [illegible]

(5) [illegible]

(6) [illegible]

$$[illegible]$$

(7) [illegible]

(8) [illegible]

(9) [illegible] of the other speeds under each condition: field off and field on. Neglect any doubtful runs or readings.

Graphs.

(1) [illegible] plot on it the torques calculated from the steady-running tests.

[illegible]

(2) [illegible]

then have tiny circles drawn round them in ink with small spring bows. A magnifying glass is of considerable assistance for these processes.

(4) When the "field on" curve is satisfactory, draw as accurately as possible the tangent at the speed n_2. The best way is to adjust an accurate straight-edge

RUNNING-DOWN TEST OF NO. 1 MACHINE. FIELD CURRENT = 175 MILLIAMPERES.

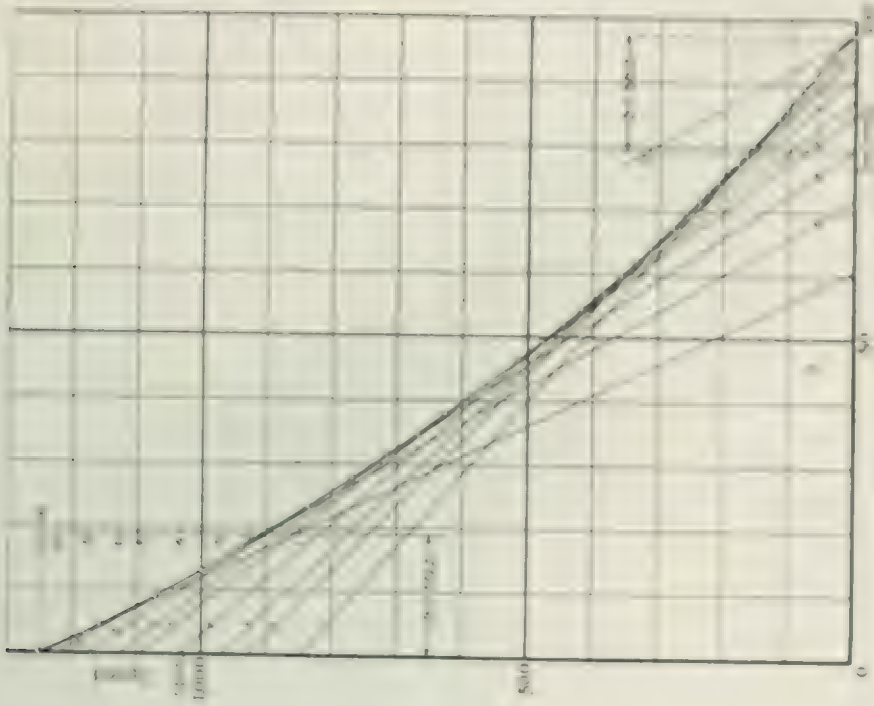
Stroboscope		Field Off, Time in Seconds					Field On, Time in Seconds					
Number of Spots	Speed, r.p.m.	2	3	8	9 4.30 p.m.	Mean	1 3.30 p.m.	4	5	6	7	Mean
1/2 × 16 / 2/3 × 12	1,250	0	0	0	0	0	0	0	0	0	0	0
,, 13	1,154	4·4	4·0	4·6	4·6	4·4	2·2	2·4	2·2	2·2	2·2	2·2
,, 14	1,071	8·6	9·0	9·0	9·0	8·9	4·2	4·2	4·4	4·6	4·4	4·4
,, 15	1,000	13·2	13·0	13·2	13·2	13·2	6·2	6·2	6·2	6·2	6·4	6·2
,, 16	937·5	17·2	16·8	16·8	16·8	16·9	7·8	8·2	8·0	8·0	8·0	8·0
1 × 12	833·3	23·6	23·4	23·0	23·2	23·3	10·8	11·0	10·8	11·0	11·0	10·9
,, 13	769·2	28·0	28·0	27·0	27·6	27·7	13·0	12·8	12·8	13·2	12·8	12·9
,, 14	714·3	31·8	31·8	31·0	31·6	31·6	15·0	14·6	14·4	15·0	14·8	14·8
,, 15	666·7	35·0	35·0	34·2	35·0	34·8	16·2	16·0	15·8	16·2	16·2	16·1
,, 16	625·0	38·2	38·2	37·6	38·0	38·0	17·6	17·8	17·2	17·8	17·6	17·6
3/2 × 12	555·6	—	43·0	42·8	43·0	42·9	19·6	19·8	—	20·0	20·0	19·9
,, 13	512·8	47·2	46·6	46·4	46·4	46·6	21·0	21·4	21·0	21·2	21·4	21·2
,, 14	476·2	49·6	49·6	49·2	49·2	49·4	22·6	22·6	22·6	23·0	23·0	22·8
,, 15	444·4	52·6	52·2	52·0	52·0	52·2	24·0	24·0	24·0	24·2	24·2	24·1
,, 16 / 2 × 12	416·7	54·6	55·0	54·6	54·0	54·6	25·0	25·0	25·0	25·2	25·2	25·1
,, 13	384·6	57·8	57·4	57·0	57·0	57·3	26·2	26·4	26·2	26·2	26·4	26·3
,, 14	357·2	60·0	60·0	59·6	59·6	59·8	27·2	27·6	27·2	27·6	28·0	27·5
,, 15	333·3	62·0	62·4	62·0	62·0	62·1	28·2	28·6	28·2	28·4	29·2	28·5
,, 16	312·5	64·0	64·6	64·0	64·0	64·1	29·0	29·4	29·2	29·6	30·0	29·2
3 × 12	277·8	67·2	67·8	67·2	66·8	67·2	30·0	31·0	30·4	30·8	30·8	30·6
,, 13	256·4	69·8	70·2	69·8	69·2	69·8	31·4	32·0	31·6	—	—	31·7
,, 14	238·1	71·6	72·2	71·4	71·2	71·6	32·6	33·2	32·8	32·6	32·0	32·6
,, 15	222·2	73·2	74·0	73·0	72·6	73·2	—	34·0	—	—	—	34·0
,, 16 / 4 × 12	208·3	74·6	75·2	74·2	73·6	74·4	33·8	35·0	34·0	34·0	34·4	34·2
,, 13	192·3	76·2	76·8	76·0	75·6	76·2	—	—	—	—	—	—
,, 14	178·6	77·4	78·0	77·4	77·0	77·4	35·0	36·0	36·2	35·8	36·0	35·8
,, 15	166·7	79·0	79·2	79·0	78·2	78·9	—	—	—	—	—	—
4 × 16	156·3	80·0	80·8	80·2	79·6	80·2	36·2	37·2	—	37·0	37·4	37·0
4/3 × 64	117·2	84·2	85·4	84·2	83·8	84·4	—	—	—	—	—	—
3/2 × 64	104·2	86·0	87·0	86·0	85·2	86·0	38·6	38·6	39·4	39·8	40·0	39·3
2 × 64	78·1	89·0	90·2	89·0	88·2	89·1	40·0	41·0	41·2	41·2	41·2	40·9
3 × 64	52·1	92·4	93·4	92·0	91·0	92·2	41·0	42·0	42·0	42·2	42·6	42·0
4 × 64	39·1	94·0	95·0	93·8	93·4	94·0	42·2	—	43·2	43·4	43·4	43·2
Stop	0	97·0	98·8	97·2	97·0	97·5	43·6	44·4	44·2	44·6	44·8	44·3

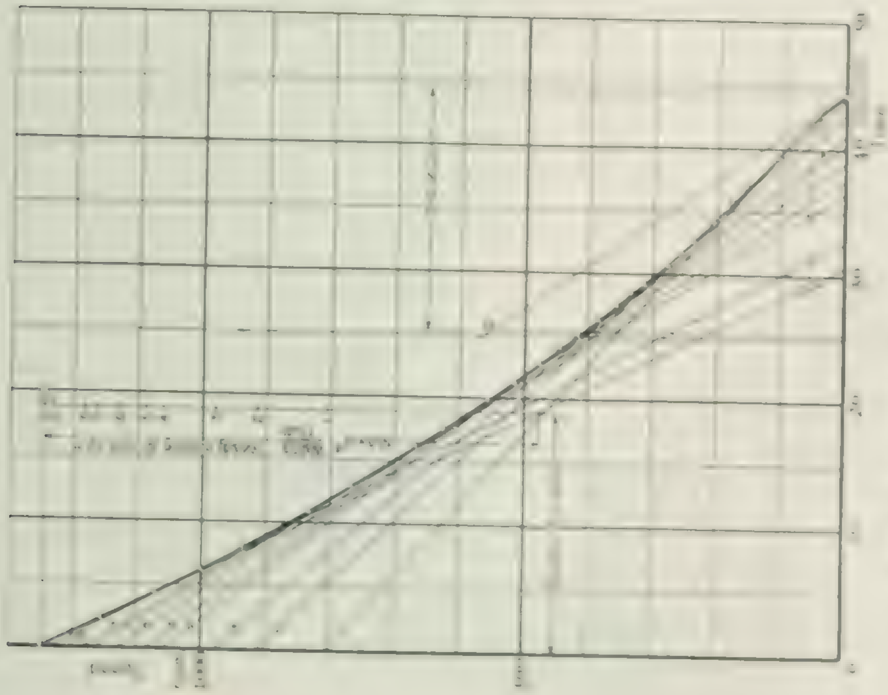
STEADY-RUNNING TESTS.

Spots	Speed, r.p.m.	Field Current Milli-amps.	Armature Current. Amps.	Brush P.D. Volts.	Watt-meter Reading. Divisions	Gross Power. Watts	Resistance E.M.F. Volts	Motion E.M.F. Volts	Volt-coil Loss. Watts	Resistance Loss. Watts	Net Power. Watts	Stray Torque, $10^{-3} \times$ watts / r.p.m.	Mean
1/2 × 16	1,250	175	0·85	483	102	408	3	486	14	3	391	313	308
2/3 × 13	1,154	175	0·81	446	91	364	3	443	12	2	350	303	

(3) With a fine pencil, draw, freehand, the best smooth curve through these points. Test it by looking along it with the plane of the paper pointing to the eye, and adjust it until it is free from irregularities. Finally, leave it lined in finely in pencil.

until it seems to give the best contact at the desired point and then mark its position at the margins of the paper. Repeat this several times without looking at the marks and take their mean. Test it by making contact just to one side and then





just to the other side of the given point. Special care should be taken with this tangent because it fixes the scale of all the other ordinates of the torque curve.

(5) Set off downwards (or upwards) along any convenient ordinate, from where it cuts the tangent, a distance equal to the ordinate which represents the torque found for the speed n_2. Through the other end of this distance draw a parallel to the time axis, and erect a second ordinate where that parallel cuts the tangent.

(6) Erect two convenient ordinates to the "field off" curve, the distance apart of which represents the same time as in the other curve.

(10) Plot on the same sheet the difference between the ordinates of the "Field on" and "Field off" curves. Draw the best straight line through the points, and label it "Difference. Magnetic."

(11) Draw a horizontal line through the intersection of the "Magnetic" line with the torque axis, and mark it "Hysteresis."

(12) Draw in the ordinate for that speed which gives the rated voltage of the machine, and label its intercepts between the various curves as follows:—

"Hysteresis" from the speed-axis to the hysteresis line.

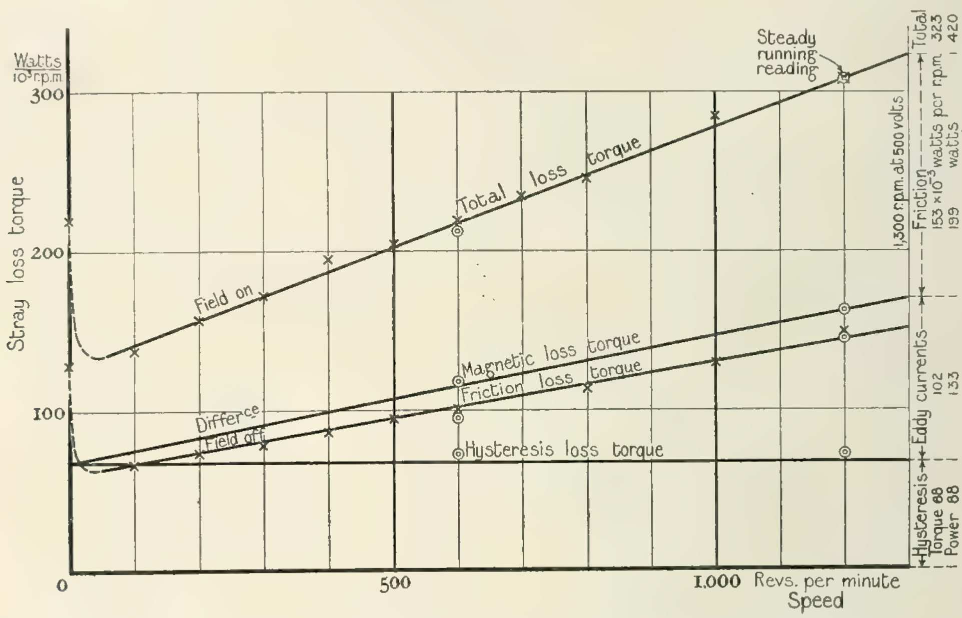


FIG. 13.—Loss Torques of a 5 h.p. Motor derived from the Running-down Curves.

The circles show the points determined by the four-point method, taken immediately after the running-down curves: see Appendix II.

(7) Draw tangents at convenient intervals along each curve, say at $n = 0$, 100, 200, 300, 400, 500, 600, 800, 1,000, 1,200, etc., r.p.m. marking them at both ends with the speed.

(8) Project the intersections of these tangents with one of the vertical lines across to the other and mark the points with the speed to which they refer. Should any of the tangents not cut both verticals, a second pair at the same distance apart may be drawn to suit them.

(9) With the dividers, measure off the distances between the points last marked and the intersections of the corresponding tangents with the same ordinate, and set them off as ordinates at the corresponding speeds for the torque-speed curves. Draw the best smooth curves through the points so obtained and label them "Field on. Total." "Field off. Friction."

"Eddy Currents" from the hysteresis to the magnetic line.

"Friction" from the magnetic to the total line.

Insert, in figures, the value of each part, and also of the corresponding power.

(13) Draw up a table of estimated losses, input, and efficiency at $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, 1/1, and $\frac{5}{4}$ load.

The table herewith and Figs. 11, 12, and 13 give the actual results of an experiment carried out in accordance with these directions. This may be taken to represent about the best that can be obtained by the method with such a quick retardation, as the students who carried it out were already familiar with the method and had acquired some skill with it.

APPENDIX II.

ANALYSIS OF THE [illegible] LOSSES OF A CONTINUOUS-CURRENT MACHINE BY THE STROBOSCOPIC RUNNING-DOWN METHODS.

Apparatus: [illegible]

Regulator for armature current, with fine adjustment.
Ammeters for field current and no-load armature current.
Voltmeter for armature voltage.
Wattmeter for no-load current and voltage (may be omitted).
Double-pole and single-pole switches for armature current and voltage.
Stroboscopic tuning fork, projection lantern, and standard stroboscopic discs.
[illegible] reading to [illegible] second.

Precautions.

As the starter will not fly back automatically, it is essential to put it in the "off" position immediately after switching off, and to [illegible] before switching on again.

If any deviations be made from the standard diagram, see that they are such that the current taken by the field discharge resistance does not pass through the [illegible] coil, the field regulator, or any instruments the readings of which are required. Also see that the connections between the field coils and this resistance cannot be broken by any of the switches, including the starting switch.

Avoid letting the machine stand between readings. Keep it at the speed n_1 during as much of the time as possible.

Do not forget to break the volt-coil circuits before making the running-down tests.

See that the main switch is pulled off when the experiment is complete.

Experiment.

(1) For some time beforehand run the machine at the speed n_1 as a motor, with its normal field, and the brushes in the neutral position.

(2) When ready to begin, set the field current exactly to the desired value and, by means of the armature regulator, the speed exactly to n_1, which brings some stroboscopic pattern to rest. This speed should be near the normal speed of the machine.

(3) Note the readings of all the instruments and the position of the brush rocker.

(4) Quickly reduce the speed without changing the field current to the next synchronous value n_2, and again read the instruments.

(5) Repeat (2), (3), and (4) several times if necessary, to see that the conditions are steady.

(6) Break the circuits of the voltmeter and volt-coil of the wattmeter.

(7) Quickly raise the speed, by the armature regulator, to about the next synchronous one, and then immediately switch off the armature and field currents by the double-pole switch.

(8) Put the starter handle to the "off" position, and [illegible]

(9) [illegible] speed [illegible] n_2. Note the time taken.

(10) Repeat (7), (8), and (9) several times.

(11) After seeing that the field current is right, repeat (7) to (10) [illegible]

(12) Repeat (7) to (11) [illegible] at $\frac{1}{2}n_1$ and stop it at $\frac{1}{2}n_2$. The experiment may be repeated with other field currents and other brush positions.

Calculations. Calculate the following:—

(1) The speeds n_1, n_2, $\frac{1}{2}n_1$, $\frac{1}{2}n_2$, $\frac{1}{2}(n_1+n_2)$ [illegible] where [illegible] is the frequency of the [illegible] given by the fork and [illegible] the [illegible] number of spots in the pattern.

(2) The total power [illegible] by the wattmeter P_w, which includes that used in its own volt-coil, in the voltmeter, and [illegible] If no wattmeter be used, the product of the ammeter and voltmeter readings must be taken instead.

(3) The [illegible] of the armature and [illegible]

(4) The [illegible] V [illegible]

(5) The power used by the armature and brush resistance. [illegible]

(6) The power used by the voltmeter and wattmeter volt-coils. [illegible]

(7) The net power used for the rotating [illegible] at each speed. [illegible]

(8) The corresponding torques. [illegible]

(9) [illegible] torque at the mean speed [illegible]

(10) [illegible] from n_1 to n_2 with the field on).

(11) The frictional torque at the speed [illegible] ÷ time taken to slow from n_1 to n_2 with field off.

(12) The magnetic torque at the speed [illegible]

(13) The total drag torque at the speed $\frac{1}{2}n$. [illegible] to $\frac{1}{2}n_2$ with field on.

(14) The frictional torque at the speed $\frac{1}{2}n$. [illegible] $\frac{1}{2}n_2$ with field off.

(15) The magnetic torque at the speed $\frac{1}{2}n$. [illegible]

(16) The eddy-current torque at the speed $\frac{1}{2}n$. [illegible]

(17) The eddy-current torque at the speed n. $t_e = 2\,t_e'$

(18) The hysteresis torque. [illegible]

(19) The power used by friction at the speed n. [illegible]

(20) The power used by eddy currents at the speed n. [illegible]

(21) The power used by hysteresis at the speed n. [illegible]

The following is a set of readings for a test by the four-point method taken immediately after the complete running-down test given in the last appendix, less than half an hour being required for the purpose. The points for this test are also plotted on the curves of Fig. 13. A similar test taken two months previously gave practically identical results; the wattmeter showed an appreciably smaller intake of power in the earlier experiment (357 against 370 watts), while the analysis shows the friction (166 against 174) and eddy currents (101 against 108) to have been less, while the hysteresis was practically the same (90 and 88).

Analysis of No-load Losses by Four-point Running-down Method.

4-*Pole Machine No.* 1 *by Mavor & Coulson. Rated at* 4 *kilowatts*, 500 *volts*, 9 *amperes*, 1,200 *r.p.m.*
Field current 0·175 *ampere. Brush rocker at* 40. *Date* 28/5/14.

Steady running at 1,250 *r.p.m.* (1/2 × 16 = 8 *spots*).

Brush P.D.	483 volts	"Motion" E.M.F. ...	480 volts	Volt-coil loss	14 watts
Armature current ...	0·85 amp.	"Resistance" E.M.F. ...	3 „	Resistance losses ...	3 „
Wattmeter reading ...	102 divisions	Gross power	408 watts	Net power	391 „
				Total stray-loss torque	313 $\frac{\text{watts}}{\text{1,000 r.p.m.}}$

Steady running at 1,154 *r.p.m.* (2/3 × 13 = 8 2/3 *spots*).

Brush P.D.	446 volts	"Motion" E.M.F. ...	443 volts	Volt-coil loss	12 watts
Armature current ...	0·81 amp.	"Resistance" E.M.F. ...	3 „	Resistance losses ...	2 „
Wattmeter reading ...	91 divisions	Gross power	364 watts	Net power	350 „
				Total stray-loss torque	303 $\frac{\text{watts}}{\text{1,000 r.p.m.}}$

Running-down Tests.

	Field			Mean
Full-speed Range. 1,250 to 1,154 r.p.m.	Off.	(1) 4·55, 4·72, 4·76, 4·87, 4·93	(5) 4·70, 4·83, 4·92, 4·87	4·80 sec.
	On.	(2) 2·29, 2·21, 2·20, 2·34		2·26 „
Half-speed Range. 625 to 577 r.p.m.	Off.	(3) 3·69, 3·68, 3·63		3·67 „
	On.	(4) 1·67, 1·55, 1·67, 1·62		1·63 „

Analysis of No-load Stray Losses.

	Half-speed. 601 r.p.m.		Full-speed. 1,202 r.p.m.	
	Torque. $\frac{\text{Watts}}{\text{1,000 r.p.m.}}$	Power. Watts.	Torque. $\frac{\text{Watts}}{\text{1,000 r.p.m.}}$	Power. Watts.
Total stray losses	213	128	308	370
Friction loss	95	57	145	174
Magnetic losses	118	71	163	196
Eddy-current loss	45	27	90	108
Hysteresis loss	73	44	73	88

APPENDIX III

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Measurement of speed by stroboscopic tuning fork.

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——— [illegible] *Science Abstracts*, vol. 6, B, No. 361, 1903.

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(6) [illegible] G. [illegible]

[illegible] are made, viz. (*a*) field on, (*b*) field off, and (*c*) field on, with a known brake torque. Curves are plotted and tangents drawn.

(7) [illegible]

(8) [illegible]

(9) [illegible]

(10) [illegible]

(11) [illegible] *I.E.E.*, vol. 31, p. 632, 1901; and also *Science Abstracts*, [illegible]

[illegible]

(12) [illegible] *Electrician*, vol. 51, p. 1049, 1903; and also *Science Abstracts*, vol. 7, B, No. 1968, 1904.

Calculations made from time taken to come to rest after switching off.

(13) [illegible] *Zeitschrift*, vol. 26, p. 610, 1905; and also *Science Abstracts*, [illegible]

Steady running and retardation tests.

(14) [illegible] *Eclairage Electrique*, vol. 44, p. 470, 1905; and also [illegible]

[illegible]

——— [illegible] from retardation and acceleration curves. *Elektrotechnische Zeitschrift*, vol. 27, p. 77, 1906; and also *Science Abstracts*, vol. 9, B, No. 321, 1906.

Determines inertia from running-down and running-up curves for same rotor current.

(15) [illegible]

(16) [illegible] *Science Abstracts*, vol. 10, B, No. 531, 1907.

[illegible]

primary of a transformer having an air-gap in its magnetic circuit. The secondary is connected to a voltmeter and gives a voltage proportional to the rate of change of the voltage of the small dynamo, and therefore proportional to the rate of change of speed. In the other method the auxiliary dynamo is connected to a condenser and galvanometer in series.

(17) SMITH, C. F. Experimental determination of the losses in motors. *Journal I.E.E.*, vol. 39, p. 437, 1907; and also *Science Abstracts*, vol. 10, B, No. 919, 1907.

Gives a very full account of the various methods of separation, and advocates the use of a special calibrated flywheel for the retardation test.

(18) DELÙ, F. Motor losses. *Association des Ingénieurs Électriciens, Bulletin, Institut Électrotechnique Montefiore, Liège*, vol. 7, p. 328, 1907; and also *Science Abstracts*, vol. 11, B, No. 414, 1908.

Gives methods of finding the moment of inertia.

(19) KAPP, G. Experimental determination of the moment of inertia of a direct-current armature. *Journal I.E.E.*, vol. 44, p. 248, 1910; also *Electrician*, vol. 64, p. 609, 1910; and also *Science Abstracts*, vol. 13, B, No. 311, 1910.

Gets inertia by comparison of acceleration and retardation curves with the same current.

(20) HERLAN, F. W. Retardation tests of electrical machines. *Electrical Review and Western Electrician*, vol. 57, p. 415, 1910; and also *Science Abstracts*, vol. 13, B, No. 870, 1910.

Gives an account of the retardation method of separating the losses.

(21) SCHMIEDEL, K. Frictional errors in electricity meters. *Verein zur Beförderung des Gewerbfleisses, Verhandlungen*, pp. 571 and 655, 1910, and p. 111, 1911; and also *Science Abstracts*, vol. 14, B, No. 473, 1911.

Application of the running-down test to the separation of the components of the resisting torque in an electricity meter.

(22) CZEPEK, R. Delineation of the retardation curves of small machines. *Elektrotechnik und Maschinenbau*, vol. 30, p. 137, 1912; and also *Science Abstracts*, vol. 15, B, No. 394, 1912.

Uses an auxiliary dynamo and a recording voltmeter of spark-record type.

(23) YITTBERG, A. A new method of determining the no-load losses of machines. *Elektrotechnische Zeitschrift*, vol. 33, p. 1158, 1912; also *La Lumière Électrique*, vol. 20, p. 401, 1912; and also *Science Abstracts*, vol. 16, B, No. 54, 1913.

Retardation determined directly as in Young's second method. See (16).

Analysis of losses in induction motors by running-down methods.

(24) BRAUN, R. Frictional losses in induction motors. *Elektrotechnische Zeitschrift*, vol. 20, p. 685, 1899; and also *Science Abstracts*, vol. 3, No. 349, 1900.

Mentions the running-down test among others.

(25) BRAGSTAD, O. S., and J. L. LA COUR. Separation of losses in induction motors. *Elektrotechnische Zeitschrift*, vol. 24, p. 34, 1903; and also *Science Abstracts*, vol. 6, B, No. 692, 1903.

Application to induction motors, getting constant by running as synchronous motor with continuous-current excitation of rotor.

26) BRAGSTAD, O. S. Separation of the losses in an induction motor. *Zeitschrift für Elektrotechnik, Wien*, vol. 23, p. 381, 1905; and also *Science Abstracts*, vol. 8, B, No. 1036, 1905.

See (25).

(27) ROEHLE, F. See (14).

(28) WALL, T. F. Iron losses in induction motors. *Electrician*, vol. 58, pp. 752 and 797, 1907; also *Éclairage Électrique*, vol. 51, pp. 23 and 60, 1907; and also *Science Abstracts*, vol. 10, B, No. 401, 1907.

(29) SMITH, C. F. See (17).

DISCUSSION ON

"THE SHAPE OF THE PRESSURE WAVE IN ELECTRICAL MACHINERY."*

MANCHESTER LOCAL SECTION, [illegible] JANUARY, [illegible]

Professor MILES WALKER: The authors are to be congratulated [illegible] the generator. It is possible then to calculate with a fair degree of accuracy the form of the magnetic field. When however the purchaser says that in the final E.M.F. wave-form there must be no ripple of more than a certain percentage of the fundamental, the designer generally finds considerable difficulty if the winding lies in slots. He does not know how to ascertain the exact E.M.F. wave-form from the wave-form of the magnetic field. That is the problem which the authors have solved very neatly. Not only have they given some analytical simplifications of the problem, but they have also worked out the values of certain winding factors which are really the kernel of the whole matter. They shew how we should proceed in order to find out the value of any ripple. Consider, for example, the seventh harmonic. From the particulars given in the table on page 218 we can tell exactly how great the seventh harmonic will be in the E.M.F. wave-form, so that the designer is now in a much better position than before this paper was written. While I think the authors are to be congratulated upon carrying the subject as far as they have done, I hope that they will be able to continue the work and carry the matter still further. As Dr. Smith said in his introductory remarks, they have confined their attention to the case of no load, which in itself is quite a big work. I am afraid that the paper hardly goes far enough to enable us to state that an alternator will not have harmonics above a certain amount when it is running under load unless we can ascertain exactly the form of the magnetic field on full load. We shall therefore hope that the authors will give us another paper dealing more fully with the matter. There are in Manchester a large number of electrical students, and a paper of this kind illustrates to them [illegible] here. I call, say, on Mr. Wheelwright, who says, "Yes, this is a very nice alternator, but what is the amount of the [illegible] five minutes I can reply "1·1 per cent," and thus get the [illegible] much more complicated than they really are. It would be [illegible] breadth of half the coil and then the expressions on [illegible]

Mr. K. M. FAYE-HANSEN: I am [illegible] paper as I am directly concerned with the [illegible] thankful to the authors for the clear way in which they have brought the matter forward. Most of the authors' conclusions are more or less known to the [illegible] manner that one can easily calculate beforehand the [illegible] form is of course a very useful expedient, but sometimes [illegible] is the question of having to use the same die for 2-phase and 3-phase windings, for parallel connections, etc. [illegible]

Professor A. B. FIELD: Without committing ourselves as to the great practical importance, or otherwise, in operation of slight discrepancies of wave-shapes, the fact remains that purchasers' specifications frequently call for [illegible]

* Paper by Messrs. S. P. Smith, D.Sc., and R. S. H. Boulding [illegible]

Professor Field.

ing importance of slight ripples by the fact that purchasers' specifications usually limit us in this respect on no load; whereas the practical conditions will always involve partial or full load. On the other hand, it is hard to specify consistently the requirements in this respect, inasmuch as the amplitudes of the voltage harmonics will be largely influenced by the exact nature of the load. They will depend upon the amount of underground cable connected, the amount and loading of the transformers in circuit, and so on. In the case of a test, the results with a water-box load will not check with those obtained by using other types of loads. There are some cases, however, which immediately interest a manufacturer, quite apart from the user. For instance, it is well known that if we wish to use delta connections in a generator, it is important to investigate the matter in advance and ensure that the magnitude of the third and ninth harmonics will allow us to employ such connections without incurring serious circulating currents. Again, the case mentioned by the authors of a turbo-generator feeding directly, without transformers, a 6-phase converter, is probably one which many of us have had experience of, to our sorrow. Unless special precautions are taken, we may find that the third and ninth harmonics give considerable circulating currents; and the losses incidental to these are greater than would appear offhand to correspond with their magnitudes, on account of the large stray and eddy-current losses associated with the comparatively high frequencies. In a number of the stations of New York and Brooklyn, the operating voltage was originally fixed at 6,600, but with provision to change over to 11,000 volts when extensions of the system render this advisable. In consequence, many of the large generators in these stations were specified to be delta-connected, so that by changing to star connections the 11,000-volt operation could be obtained with the same winding. This is an illustration of a case of large machines in which one might otherwise be somewhat reluctant to use a delta connection. In many of these, however, the turbo-generators had their stators wound with a two-thirds coil-pitch, which completely eliminates the third and ninth harmonics. In this connection, one might perhaps take some exception to a remark of Dr. Smith's to the effect that on alternator work we nearly always have full-pitch windings. In the United States it is quite usual to have chorded windings on alternator stators, particularly in the case of turbo-generators. One case of some interest might be mentioned of the comparatively big effect of a very small harmonic. In such a machine as that referred to above, the winding was of the type described by the authors as a double-layer winding, and the stator coils were chorded so that the coil pitch was not quite two-thirds of the pole-pitch, the difference being one slot-pitch. The effect of such a chording would be almost completely to wipe out the third harmonic, the only remnant being that corresponding to the discrepancy of one slot. We might therefore expect the value of the third harmonic to be negligibly small; on the other hand, if we consider the circuit through which a third-harmonic current would circulate in the delta, we find that the path doubles back upon itself in every slot except three per pole, in which slots the current flows in the same direction in the conductors of the two coils located there. In this way the natural reactance which opposes the circulation of a third-harmonic current has also been eliminated almost entirely, so that even a very small voltage effect may give us an appreciable circulating current in the delta. This matter showed itself by the burning-out of the stator winding once or twice, on every occasion the fault developing in one of the few slots which carried two coils of one phase. These machines were built a number of years ago before very much attention was paid to the question of losses in deep solid conductors on account of the cross-slot flux; and this particular winding was arranged with two strips deep in the slot, the depth, or width, of each strip being considerably greater than we should use at the present time. Now, the extra losses to be anticipated in the conductors of the few special slots, compared with those of the other slots, would be as follows: In the first place, the main currents in the lower and upper layers of conductors are in phase with one another, instead of being 60° apart, and this results in heavier eddy-current losses in the outer conductors of these slots. Secondly, with regard to the triple-harmonic current circulating in the delta, this also maintains the same phase in the two layers of these special slots, but is 180° apart in the two layers of all other slots. On account of the high frequency of the third harmonic, a comparatively small circulating current is responsible for large eddy-current losses in the outer conductors of those slots having no phase-difference between the two layers, whereas in the other slots this loss is no greater in the outer conductors than in the inner ones, on account of the 180° phase difference. There seems very little question but that the failure of the winding was due to this last cause, and no further trouble was encountered after changing the coil-pitch to exactly two-thirds of the pole-pitch, and slightly changing the insulation. In conclusion, I should like to draw attention to the importance of the curves in Fig. 21, and for comparison Fig. 16. These appear to me to illustrate a matter of considerable importance which is apt to be overlooked: namely, the harm of having the rotor slot-pitch nearly equal to the stator slot-pitch.

(*Communicated*): I wish to correct a misunderstanding of my remarks evinced by Dr. Smith's verbal reply at the meeting. In the case of the large delta-connected turbo-generator to which I referred, the winding was entirely symmetrical, there were no parallel circuits, the stator coils were all alike and of the same span, and the three phases were identical, except for their relative 120° displacement. The number of stator slots per pole per phase was an integer. The point upon which I wish to lay stress was that by using a coil-span differing from two-thirds of the pole-pitch by one slot-pitch, there remained in the phase-voltage wave some remnant of the third harmonic which occurred in the conductor-voltage wave. In a delta-connected winding, if there is any third or ninth harmonic in the phase voltage, this element of voltage becomes of the same phase in the three legs of the winding, and results in a net circulating current, as is well understood. I think no builder of reputation would construct such machines as I was referring to with unsymmetrical circuits or with parallels which were not "identical."

Dr. Worrall.

Dr. G. W. WORRALL (*communicated*): This paper is useful if only as a comprehensive collection of matter well known to designers and other engineers who have

[illegible] and the other a high-speed turbo-alternator after eight years' running. [illegible] Some of the methods adopted are described in the paper. The authors give no scales on any of the diagrams; some of the waves may be at high voltage, in which case considerable ripples may be present even in a wave which may be apparently smooth. The mathematical treatment of the subject, while useful for calculating magnitudes, is not, I think, the best method of explaining phenomena, and I find a physical explanation much more effective. For instance, the presence of the break of continuity referred to on page 225 near the top of the left-hand column can be quite easily explained without the artificial device of resolving the ripple into two harmonics; and when it is borne in mind that there is not the slightest ground for assuming that the ripple is a sine wave the physical method is much more accurate.

Messrs. S. P. Smith and R. S. H. Boulding (in reply): We are very grateful for Professor Walker's appreciative [illegible]

[illegible] number of slots per pole, the effects could be studied by [illegible]

[illegible] the ripple in the conductor pressure are discussed. To [illegible] from Dr. Worrall's point of view—to expect designers to be able to produce machines that can be guaranteed [illegible] a sine wave for the flux distribution [illegible] phenomena, the analytical investigation enabled an insight to be obtained into the magnitude and phase relations of these effects, and in this the fundamental certainly plays the chief part.

MEMBERS ON MILITARY SERVICE.

(SECOND LIST.*)

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Clirehugh, S. V.	6th Royal Sussex Regt.	Corporal
Davy, C. W.	Royal Engineers	Lieut.-Col.
Eden, A.	National Reserve (Artillery)	Lieutenant
Ionides, P. D.	16th Middlesex Regt.	Lieutenant
Jackson, Sir H. B., K.C.B., K.C.V.O., F.R.S.	Royal Navy	Admiral
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McKeever, F. L.	102nd Regt. Canadian Force	Private
Morcom, R. K.	Divisional Engineers, R.N.D.	Lieutenant
O'Shaughnessy, J. J. F.	London Signal Service, R.E.	Major
Richardson, H.	City of Dundee (Fortress) R.E.	Captain
Sellon, E. M.	13th Batt. Canadian Force	Lieutenant
Thorn, C. H. R.	London Electrical Engineers, R.E.	Captain
Webb, G. R.	1st G.I.P. Railway Volunteers	Lieut.-Col.

Associate Members.

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Anness, E. G.	London Electrical Engineers, R.E.	Sapper
Ash, H. D.	3rd County of London Yeomanry	Lance-Corpl.
Barber, L.	United Provinces Horse	Trooper
Barnes, S. P.	Divisional Engineers, R.N.D.	Lance-Corpl.
Barney, L.	Royal Naval Air Service	1st Class Air Mechanic & Observer
Bland, C. R.	Calcutta Light Horse	Corporal
Bosworth, H. W.	Anti-Aircraft Corps (R.N.V.R.)	Able Seaman
Britton, H. E.	4th South Midland (Howitzer) Brigade, R.F.A.	Gunner
Brydon, A. W.	6th Cheshire Regt.	Lieutenant
Buchanan, E. V.	Canadian Engineers	Captain
Bumpus, B. E.	Bombay Volunteer Rifles	Private
Burton, W.	London Electrical Engineers, R.E.	Sapper
Challis, L. S.	Queen's Westminster Rifles	Captain
Culligan, F. J.	Calcutta Scottish Volunteers	Private
Curgenven, L. W.	Royal Navy	Eng. Lieut. Commander
Dermer, L. H. C.	Honourable Artillery Company	Lance-Serg
Dobell, H.	Divisional Engineers, R.N.D.	Lieutenant
Ellis, M. I. W.	Cheshire Brigade, R.F.A.	2nd Lieut.
Ellis, T.	13th Argyll & Sutherland Highlanders	Lieutenant
Fuller, A. C.	Royal Engineers	Captain
Gardiner, B. C.	Royal Marine Light Infantry	Captain
Goolding, C. L.	London Electrical Engineers, R.E.	Sapper
Hammersley-Heenan, J.	McGill University Battalion	

* See page 199.

Associate Members—*continued.*

Name.	*Corps, etc.*	*Rank.*
Harrop, D.	Divisional Engineers, R.N.D.	Sergeant
Haworth, H. F.	London Electrical Engineers, R.E.	2nd Lieut.
Hindle, J. N.	London Electrical Engineers, R.E.	Sapper
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Hulton, R. P.	Divisional Engineers, R.N.D.	Sapper
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Layton, A. B.	4th South Lancashire Regt.	Captain
Leslie, R. C.	Grenadier Guards	Private
Lord, A. F.	Devon (Fortress) R.E.	Lieutenant
Marvin, E. M.	Royal Engineers	2nd Lieut.
Maybury, P. T.	Royal Garrison Artillery	2nd Lieut.
Moberly, C. N.	Bombay Volunteer Rifles	Captain and Adjutant
O'Brien, H. E.	Royal Engineers	Captain
Palmer, J. H.	20th Royal Fusiliers	Qmr.-Sergt.
Payne, L. S.	R.N.V.R.	Sub-Lieut.
Puttick, A. W.	Bombay Volunteer Rifles	2nd Lieut.
Read, A. H.	Divisional Engineers, R.N.D.	Sapper
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Routledge, L. G. F.	Divisional Engineers, R.N.D.	Sapper
Shaw, R.	Divisional Engineers, R.N.D.	Sapper
Smith, B. H.	Divisional Engineers, R.N.D.	Qmr.-Sergt.
Sotheby, W. E.	British Red Cross	Motor Driver
Spencer-Phillips, R. J.	Anti-Aircraft Corps (R.N.V.R.)	Able Seaman
Staniar, H. D.	East Lancashire R.E.	Sergeant
Stevens, E. J.	Royal Artillery	Captain
Stovold, H. W.	Royal Engineers (Attached)	Captain
Suggate, C. F. D.	Army Ordnance Corps	Lieutenant
Sutcliffe, W.	Army Service Corps	Lieutenant
Wade, C.	British Red Cross	Motor Driver
Wallis, T. S.	Divisional Engineers, R.N.D.	Sapper
Watson, A. G.	Divisional Engineers, R.N.D.	2nd Corpl.
Williamson, G. W.	3rd Manchester Regt.	2nd Lieut.
Wolstenholme, C. S.	12th Durham Light Infantry	Lieutenant
Wynne, E. R.	Royal Engineers	Sapper

Associates.

Name.	*Corps, etc.*	*Rank.*
Clapham, C. F.	Attached to General Headquarters	
Hughman, E. M.	42nd Deoli Regt., Indian Army	2nd Lieut.
Robertson, A. B.	Highland Signal Service, R.E.	Major
Sitwell, N. S. H.	Royal Artillery	Major
Wilson, A. M., M.D.	Union of South Africa Defence Force (Medical Section)	Major

Graduates.

Name.	*Corps, etc.*	*Rank.*
Booth, H. I.	Divisional Engineers, R.N.D.	Sapper
Bracher, W. S.	Royal Army Medical Corps	Lieutenant
Chesterton, P. H.	1st Calcutta Volunteer Rifles	Private
Dees, B	Essex (Fortress) R.E.	Captain
Leggett, B.	London University O.T.C.	Cadet
McLean, W. G.	Calcutta Scottish Volunteers	Private
Stokes, W. G.	Divisional Engineers, R.N.D.	Sapper
Warburton, P. A. E.	New Zealand Engineers	Sapper
Wolf, E. M.	9th County of London Regt.	Private

Name	Unit, &c.	Rank
[illegible], S. O.	Royal Engineers	2nd Lieut.
[illegible], A.	Royal Engineers	2nd Lieut.
[illegible], H. G.	Divisional Engineers, R.N.D.	
[illegible], F.	Divisional Engineers, R.N.D.	Sapper
[illegible], L. W. F.	Divisional Engineers, R.N.D.	Sapper
[illegible], H. E.	[illegible] Manchester Regt. (Territorial)	Corporal
[illegible], H. O.	[illegible]	Lance-Corporal
[illegible], F. S.	[illegible]	Sapper
[illegible], N. E.	Public Schools Batt.	Private
[illegible], C. M.	[illegible]	2nd Lieut.
[illegible], A. E. W.	[illegible]	2nd Lieut.
[illegible], E. L.	[illegible] Regt.	[illegible]
[illegible], C. S.	[illegible]	Private
[illegible], G. F.	Divisional Engineers, R.N.D.	Sapper
[illegible], F. C. W.	[illegible] West Yorkshire Regt.	[illegible]
[illegible], F. A. J.	[illegible] R.E.	Sapper
[illegible], J. W.	Royal Engineers	Sergeant
[illegible], W. H. J.	Divisional Engineers, R.N.D.	Sapper
[illegible], William	[illegible]	Private
[illegible], G.	[illegible]	Lance-Corpl.
[illegible], F. H.	[illegible] R.E.	Sapper
[illegible], J. A. E.	Royal Engineers	2nd Lieut.
Hews, C. J.	[illegible] R.E.	2nd Corpl.
Lovegrove, C. G.	[illegible]	Private
McDougald, L. A.	[illegible]	[illegible]
[illegible], R. W.	Royal Garrison Artillery	2nd Lieut.
[illegible], D. K.	[illegible] Regt.	Sergeant

Name	Unit, &c.	Rank
[illegible], [illegible]	Divisional Engineers, R.N.D.	Sapper
[illegible], [illegible]	[illegible]	[illegible]
[illegible], C. W.	[illegible] Regt.	[illegible]
[illegible], [illegible]	Royal Engineers	[illegible]
[illegible], [illegible]	Royal Engineers	[illegible]
[illegible], H. D.	Divisional Engineers, R.N.D.	Sapper
[illegible], D. E.	[illegible] Engineers, R.E.	Sapper
[illegible], [illegible]	[illegible]	[illegible]
[illegible], C. R.	[illegible]	[illegible]
[illegible], [illegible]	[illegible]	[illegible]
Priestley, A.	Divisional Engineers, R.N.D.	Sapper
[illegible], M. A.	[illegible]	[illegible]
[illegible], M. [illegible]	Divisional Engineers, R.N.D.	Sapper
[illegible], [illegible]	[illegible]	[illegible]
[illegible], F. O.	[illegible] Regt.	[illegible]
[illegible], [illegible]	[illegible]	2nd Lieut.
[illegible], H. J.	Divisional Engineers, R.N.D.	Sapper
[illegible], M.	Royal Engineers	2nd Lieut.
[illegible], E. H.	[illegible]	Private
[illegible], [illegible]	[illegible] Artillery Volunteers	[illegible]
[illegible], J. G. W.	[illegible] Regt.	[illegible]
[illegible], G. N. [illegible]	[illegible]	[illegible]
[illegible], A. W.	[illegible]	[illegible]
[illegible], F.	Divisional Engineers, R.N.D.	Sapper

INSTITUTION ANNOUNCEMENTS

ASSOCIATE MEMBERSHIP EXAMINATION

An examination will be held on Friday and Saturday, the 30th April and 1st May, at the Examination Hall of the Royal College of Physicians and Surgeons, Queen-square, Bloomsbury, W.C. Should a sufficient number of candidates make application, arrangements will be made for the examination to be held concurrently in local centres.

Entry Forms, which must be returned not later than the 1st March, may be obtained together with the Examination Regulations on application to the Secretary of the Institution.

ACCESSIONS TO THE LENDING LIBRARY

CHRISTIE, C. V. Electrical engineering.
8vo. [illegible] pp. New York, 1913

CRAMP, W., and SMITH, C. F. Vectors and vector diagrams applied to the alternating current circuit.
8vo. 208 pp. London, [illegible]

DWIGHT, H. B. Transmission line formulas for electrical engineers, etc. 8vo. [illegible] pp. London, 1913

[illegible], E. T. Factory administration and accounts. With . . . The general problem of industrial works design, by A. Home-Morton ; and Financial accounts, by [illegible]. 8vo. [illegible] pp. London, 1914

[illegible], A. P. M., and [illegible] [illegible] 8vo. [illegible] pp. London, 1914

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8vo. [illegible] pp. London, 1914

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KAYE, G. W. C. X rays, an introduction to the study of Röntgen rays. 8vo. [illegible] pp. London, 1914

KENNELLY, A. E. Tables of complex hyperbolic and circular functions.
4to. [illegible] pp. Cambridge, Mass., 1914

[illegible], A. J. Commercial engineering.
8vo. [illegible] pp. Manchester, 1913

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8vo. [illegible] pp. London, 1914

[illegible], W. J. Practical and experimental wireless telegraphy. A handbook for operators, students and amateurs. [illegible] 8vo. [illegible] pp. London, 1914

[illegible], S., and [illegible], E. Electric systems and transmission engineering. 8vo. [illegible] pp. London, 1914

STANLEY, R. Text-book on wireless telegraphy.
8vo. [illegible] pp. London, 1914

WARDALE, W. T. Wiring electrical installations.
2nd 8vo. [illegible] pp. London, 1914

HEATING OF BURIED CABLES.

Introductory.

A first report was published last year in the *Journal** on the investigation now being conducted by the National Physical Laboratory under the auspices of the Research Committee of the Institution. The following additional information in regard to the work done during 1914 has since been supplied by the Laboratory. It is regretted, however, that the absence on military service of certain members of the Laboratory staff has affected to some extent the programme of work which had been proposed, but the greater part of the tests arranged for this winter have been or will be carried through. Offers to lend some of the cable necessary for the Laboratory tests have been made to the Committee, who desire to record their appreciation.

FURTHER REPORT OF THE NATIONAL PHYSICAL LABORATORY.

Tests with Special Loads.

At Bristol a series of tests extending over a period of rather more than three weeks was carried out on a number of cables, laid direct in the ground, of sizes ranging from 0·05 sq. in. to 0·3 sq. in.

The suggested method of measuring the resistance of the conductor by a bridge method, superimposing on the alternating current a small continuous current was used and found to be, for this case at any rate, quite satisfactory. The accuracy of the measurement of the resistance of the conductor, with the portable apparatus used, was of the order of 0·1 per cent. The current, however, could not be kept constant to nearer than ± 1 per cent, and these variations naturally limit the final accuracy of the tests.

* Heating of buried cables. *Journal I.E.E.*, vol. 52, p 779, 1914.

Determinations were also made of the amount of the moisture in the soil at the actual depth at which the cables were laid and of the temperature of the soil. It was also arranged with the mains superintendent for further determinations to be made by his staff of the amount of moisture in the soil from time to time as they opened up ground in various parts of the town.

At Wolverhampton tests were made on 0·5 and 0·75 sq. in. cables, one laid in a duct and the other solid in bitumen.

The supply was continuous current, and the accuracy of the tests was dependent only on the variations of the load.

Tests under Normal Conditions of Load.

At St. Marylebone tests have been made with a 2 sq. in. cable carrying up to 2,400 amperes for about 14 hours a day.

Temperature Recorder.

It has been possible by slight modification of the Callendar recorder to make it suitable for the purpose of obtaining records of the temperature of cables under normal conditions of loading. This instrument has therefore been purchased, and is now in use.

Arrangements were made to install the recorder and to make a number of tests, during December, at St. Marylebone with a number of 1 sq. in. cables in a 20-way duct, and during January at Wolverhampton with cables laid solid and drawn into 4- or 6-way ducts.

The thanks of the Committee are due to the authorities at Bristol, St. Marylebone, and Wolverhampton, who took great interest and did everything possible to forward the work, both by giving assistance and by making arrangements for the various tests.

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CONDITIONS AFFECTING THE VARIATIONS IN STRENGTH OF WIRELESS SIGNALS

By Professor E. W. Marchant, D.Sc., Member.

[illegible]

[illegible]

[illegible] drew attention to the remarkable difference in the strength of signals received by day and by night, and his observations have been repeated and recorded by many other [illegible]

[illegible] have been covered at night by [illegible] Said with a standard 1·5 kw. set were received at Liverpool with great clearness on Sunday evening, 14 June, [illegible]

[illegible] is a matter that requires further investigation. Theories involving the reflection and refraction of the electro- [illegible] Eccles,‡ Kennelly,§ Erskine-Murray,‖ and others, but it is very difficult to express an opinion as to their validity without accurate experimental data. Although many records have been taken, very few of these give actual [illegible] view of securing such information that the following [illegible]

[illegible] is confined to (1) observations of the effects [illegible] purpose a series of observations, [illegible]

[illegible] night.

The stations between which most measurements have been made are Liver[illegible] Some results are [illegible]

[illegible]

Special mention may be made of the results published by H. Mosler in August, 1913.* These experiments are [illegible] between Norddeich and a station lying 420 km. east of it, the transmission being entirely over land. Measurements [illegible] not affected by the altitude of the sun. The ratio between [illegible] being greatest in the spring and autumn and least during June, when the ratio was only 1·04. The [illegible]

[illegible] observed on the recording gal[illegible] strength of signal [illegible]

Another experimenter on the same subject is A. H. [illegible]

* A. H. [illegible]

† [illegible]

‡ W. H. Eccles. [illegible]

§ A. E. Kennelly. [illegible]

‖ J. Erskine-Murray. [illegible]

* H. Mosler. [illegible]

the University of North Dakota and stations on the east coast of America, 1,200 miles distant. He came to the conclusion that the best condition for signalling was when the intervening space was cloudy. Signals were not so strong on a clear day, or in bright sunshine.

Some further observations have recently been published * by him on the relation between good transmission and weather conditions. The main result confirms his previous observations, that the most favourable condition for signalling over land is cloudy sky. The same conclusion was suggested by the author in a paper read before the British Association.† Taylor shows that this result cannot be explained by the reduced ground absorption after heavy rainfall, but must be due to variations in the absorptive capacity of the intervening medium. He suggests that the radiation received from a transmitting station may be divided into three parts:—

(1) The portion reflected from the cloud level, *i.e.* the part which is propagated between two parallel surfaces formed by the earth and by the clouds.

(2) The portion entering the "middle," ionized region and refracted (this portion is more absorbed by day than by night).

(3) The portion passing through the middle region and reflected on the upper permanently ionized layer of atmosphere (this portion is almost entirely absent in daylight, but would become powerful at night).

The large variation at night may be due to changes in the amount of energy reflected from the upper ionized layer. The chief interest in Taylor's paper lies in his suggestion that there is a distinct difference between the medium below and above the cloud-level.

Some very interesting results have been published by Lutze,‡ who has made experiments with balloons, making double flights, one at a low altitude and the other at a much higher one. He investigated the variation in signal strength on these two balloons, using similar aerials on them and employing a shunted telephone method of estimating it. For these experiments a special set of signals was sent out from the Eiffel Tower station at quarter-hour intervals. He found that the signal strength did not appear to change very much until an altitude of 1,000 to 1,500 metres was attained, but that at altitudes of 5,000 metres and over, it fell to less than 10 per cent of the value that was observed at the lower levels. The transition from strong to weak signals with changing altitude seems to be comparatively sudden and to take place at a height of between about 2,500 and 3,500 metres.

In one flight in which the records have been particularly complete, he shows that at the lower and higher levels the moisture in the atmosphere was considerable, that the air currents at the lower level were from the south, and that at the higher level they were from the west. Both these currents appear to have been saturated with moisture.

* A. H. TAYLOR. Radiotransmission and weather. *Physical Review*, vol. 3, series 2, p. 346, 1914

† E. W. MARCHANT. Effect of atmospheric conditions on the strength of signals received at Liverpool from Paris and some other places, together with an account of the diurnal variation in the energy received. *British Association Report*, 1914, p. 607.

‡ *Abhandlungen der Naturwissenschaftlicher Gesellschaft zu Halle*, vol. 1, 1914.

Between the two levels, however, there was a comparatively dry layer of air and the signal strength weakened after the balloon passed through this layer on its upward flight.

It is difficult to say whether there is any relation between the presence of this air layer and the signal-strength variation, but the results that Lutze has obtained would seem to be of great value in their bearing on the theory of transmission. They seem to provide clear evidence that there is, on a much lower level than has previously been suggested, a mass of ionized air which absorbs a considerable amount of the energy of the transmitted electromagnetic waves.

Marconi has described the changes which take place in the strength of signals transmitted across the Atlantic; the curve showing the remarkable strengthening of the signal about an hour after sunset at Glace Bay and about an hour before sunrise at Clifden is well known, and Dr. Eccles has based his theories very largely on these results.*

L. W. Austin,† in some experiments made to compare the efficiency of arc and spark transmission, states that the signals are weakest during July and August. These tests were made, however, with wave-lengths of from 3,500 to 7,000 metres and between places 1,780 miles apart.

Howe ‡ has shown that the current received by an antenna at a great distance from the transmitter, on the assumption of a perfectly conducting earth and a non-ionized atmosphere, is much smaller than that actually found by experiment, thus strongly supporting the theory of reflection or refraction due to ionization of the upper atmosphere.

Kennelly,§ in discussing the observed changes of the intensity of signals near sunset and sunrise, arrives at the conclusion that they may be explained by reflecting effects on the boundary surface or shadow wall between darkness (air of small conductivity) and illumination (air of marked conductivity).

According to his theory there should be a dip in the curve of signal strength at sunset between two places lying north-west and south-east of each other, at the summer solstice, *i.e.* when the shadow band crosses the line between the two places. The curve given in Fig. 4 shows no appreciable dip in the records obtained in July, whereas there does seem some slight evidence of diminution in strength when the shadow band lies between the two places on 27 March and 11 October (Fig. 5).

K. E. F. Schmidt has obtained positive results of the increase in signal strength at night (over a distance of 8 km.) of the order of 30 per cent in December. In some experiments made between Norddeich and Halle, 400 km. apart, the ratio of intensity between night and day in October 1911 was 1·47 measured on a barretter. The corresponding figures found with a shunted telephone are interesting from the point of view of the accuracy of this method of observation. He finds the ratio varies from 0·56 to 2·37 by shunted telephone, whereas the corresponding variation with the barretter is from 1·4 to 1·47. This result is entirely borne out by the author's

* G. MARCONI. Transatlantic wireless telegraphy. *Proceedings of the Royal Institution*, vol. 10, p. 107, 1908.

† *Journal of the Washington Academy of Sciences*, vol. 3, p. 517, 1913.

‡ G. W. O. HOWE. The transmission of electromagnetic waves through and around the earth. *Electrician*, vol. 72, p. 484, 1913.

§ *Loc. cit.*

[illegible] by A. [illegible] and O. [illegible]

[illegible] considerable difference between night and day [illegible] and show that the [illegible] between one [illegible] and another. [illegible]

On [illegible] October [illegible] is slightly greater at Nancy than it is in Liverpool. [illegible]

Methods of Observation

In order to obtain comparable measurements of signal strength it is of importance that the aerial circuit should [illegible] Where these ideal conditions cannot be obtained absolute measurements are of little value, but the figures which [illegible] should give reliable comparisons between signal strengths from day to day.

[illegible] over land which is covered with buildings, and consequently [illegible] not correspond very closely with that found by calculation [illegible]

[illegible] by an antenna is the [illegible] which the ground has good conductivity.

[illegible]

[illegible]

[illegible] conjunction with a high-frequency (500 pe[illegible] inductances of the aerial circuit were also measured by the mutual variable standard.

The resistance of the secondary circuit was estimated [illegible] this means, a curve connecting current and resistance in the circuit can be drawn and, by extrapolation, the resistance of the circuit itself can be found. This result was [illegible] methods and also by measurements of the decrement of the circuit as described below. The [illegible] tore, the coil resistance in this circuit are [illegible]

[illegible] obtained. The natural frequency of this oscillating circuit [illegible]

The decrement of the secondary circuits was determined [illegible]

It is difficult to measure the earth resistance of the antenna circuit, but the determination of the decrement of the signals received enables the constancy of the resistance of the earth to be determined to any required degree of accuracy.* It was found that the decrement did not vary very much from day to day, and in making calculations of received energy, the earth resistance has been assumed constant.

Measurement of Current in the Crystal Circuit.

The current received by the antenna was estimated from the current flowing through the crystal circuit, as explained above. As far as variations are concerned, it was sufficient to note the changes in the galvanometer currents, due to the received signals. The crystal combination used in nearly all the tests was the one known as perikon, with crystals of zincite and chalcopyrite.

in the circuit depends on a thermo-electromotive force induced by the heating effect of the oscillating current.

It has been shown by Eccles and others that the law of variation of current in the crystal circuit with variation in current in the oscillating circuit varies with the magnitude of the oscillating current, and that the action of the crystal approximates more closely to a pure valve action for large currents.

With the currents used in these experiments (the maximum value usually not exceeding 2 micro-amperes) the square law is accurately true. Other crystals that have been tried are combinations of zincite and galena, brass wire and silicon, and iron wire and silicon.

With a particularly sensitive silicon crystal it was found that the iron-wire-silicon combination was almost as sensitive as the perikon, but this combination was not as reliable as the perikon, *i.e.* the sensitiveness of the

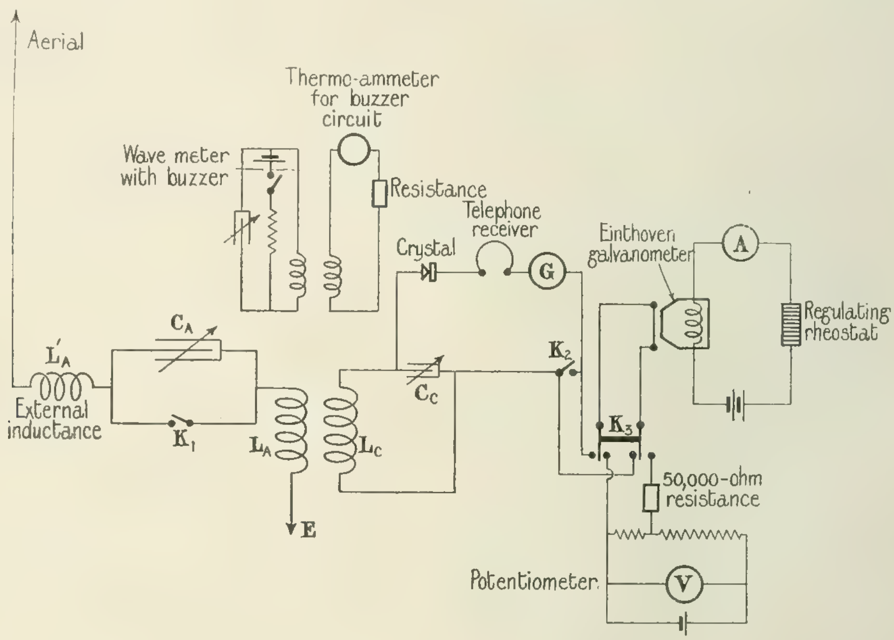


Fig. 1.—Receiver Circuit.

In order to simplify the work as much as possible, the secondary circuit was calibrated on the same wave-length as that of the received signal. This not only surmounts the difficulty that the sensitiveness of the crystal may depend upon the frequency of the currents passing through it, but, as is shown in the appendix, it enables the antenna current to be determined directly in terms of the current in the buzzer circuit by using a constant multiplier.

As has been shown by the author † and many others, the current flowing in the crystal circuit connected to any oscillating system is proportional to the square of the oscillating current. This result has been checked in connection with all the crystals used in the experiments.

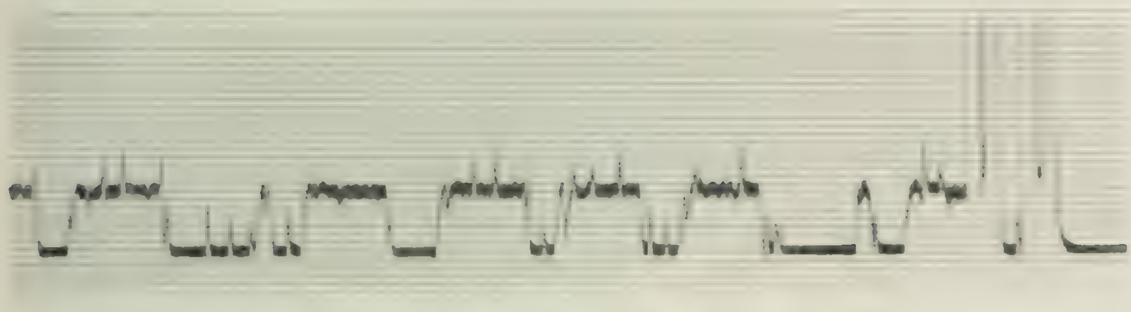
It may be interesting to note that this result appears to show that the action of these crystals is not a valve action, but one in which the magnitude of the current flowing

crystal was more liable to be upset by atmospheric discharges and, for this reason, the perikon has been preferred in all these tests.

In series with the crystal was placed a high-resistance (8,000 ohms) telephone receiver, an ordinary Broca galvanometer with a period of about 9 seconds, and an Einthoven galvanometer with a silvered quartz fibre having a natural period of about 1/20 second when working at normal sensibility. It might have been expected that for long dashes the Broca galvanometer would have proved satisfactory and sensitive enough for the purpose. The actual deflection of the instrument for a given current in the circuit is greater than that of the Einthoven, the normal sensitiveness of the instrument being 400 mm. per micro-ampere, but in practice it was found that extraneous causes made it almost impossible to use the Broca galvanometer for purposes of measurement. The greatest difficulty was met with in connection with the atmospheric discharges which at certain times of the year are liable

* Assuming that the decrement of the wave train emitted is constant.
† E. W. Marchant. The measurement of the strength of wireless signals. *Year Book of Wireless Telegraphy*, p. 513, 1914.

[illegible]



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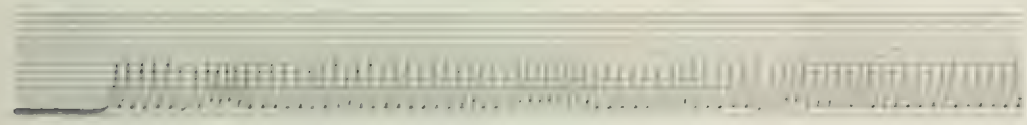

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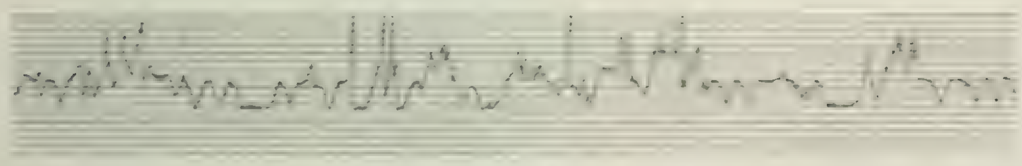

[illegible]

[illegible] weak signals the greater magnification was used, Fig. 2.

[illegible] meter observations afterwards [illegible]

the Broca and Einthoven instruments being maintained as nearly constant as possible.

The buzzer used in most of the tests was the double contact breaker supplied with the Lorenz wave-meter. It will be noted that the current in the buzzer circuit was not measured by a direct-reading instrument inserted in it. It was found much more satisfactory to couple the Duddell thermo-ammeter by means of a secondary coil wound on a fixed frame and arranged so that the coil of the wave-meter was concentric with it. This coil was connected through a non-inductive resistance to the Duddell thermo-ammeter. By this arrangement it was possible to use a small current thermo-ammeter and to adjust the sensitiveness of the instrument by varying the resistance in the circuit. The current flowing in the secondary coil could be reduced to such proportions that there was no appreciable change in the current flowing in the wave-meter circuit when the secondary circuit was closed. This arrangement had also the advantage of making no appreciable change in the natural period of the wave-meter circuit. If the instrument were placed directly in the wave-meter circuit the inductance of the leads made a considerable alteration in the natural period of the wave-meter.

The accuracy of the measurements of signal strength is not closer than ±5 per cent, and too much attention should not be given to small variations or irregularities in the curves.

Observations on Signal Strength.

Sunset effect.—One of the earliest observations in connection with wireless telegraphy was that it was possible to transmit over much longer distances by night than by day, and it has been a matter of discussion ever since as to what is the cause of that variation. Several observations have been made at the time of sunset, and the results are recorded in Figs. 4, 5, 6, 12, 13, and 14. The first point

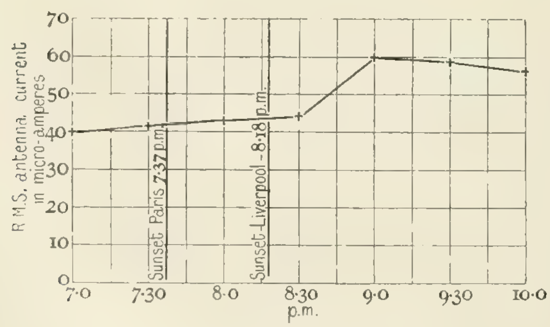

Fig. 4.—Paris Sunset Test, 26 July, 1913. Paris Antenna Current, 43–45 amperes. Weather clear.

which deserves notice (which was mentioned by the author in a preliminary account of these tests at Birmingham) is that the increase in strength of the signal does not occur at the time of sunset but some time afterwards. This is what might have been expected if the state of ionization of the atmosphere is the controlling factor in determining the signal strength. The increase in signal strength occurs at almost the same time as daylight ceases, *i.e.* at the same time as the number of ions per cubic cm. in the atmosphere would rapidly diminish.

Observations in America appear to show that with places lying due east and west of each other there was weakening* in the strength of the signals while the dark-light band lay between the two places. This effect is of course well known in connection with the transatlantic transmission. It will be noticed from the curves that there is little evidence of such an effect occurring between Liverpool and Paris. If this effect occurs it is, comparatively, very slight. It would seem, therefore, that the "fog" in the

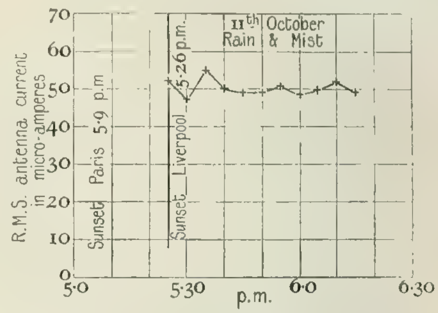

Fig. 5.—Paris Sunset Test, 11 October. Paris Antenna Current, 43–45 amperes.

space covered by the dark-light band is not a very dense one.

The curves show, however, that the sunset effect varies with the weather conditions at the time of sunset. On 26 July (Fig. 4) and 27 October (Fig. 6) the sky was clear and the effect was what may be called of the "normal" type, *i.e.* there was an increase in strength commencing from ¾ hour to 1 hour after sunset. On these days, however, the antenna current measured before sunset was only 40 micro-amperes. On 27 October the rise in strength was perceptible at 5.35 p.m., the time of sunset being 4.38 p.m.; on this day sunset occurs at the same

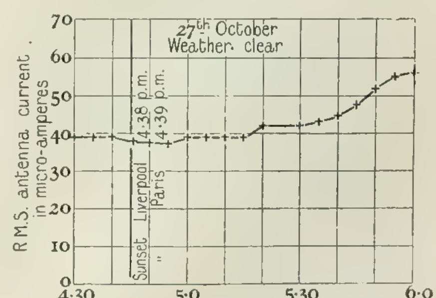

Fig. 6.—Paris Sunset Test, 27 October. Paris Antenna Current, 43–45 amperes.

time in Liverpool and Paris. In December 1913 and January 1914, for which the curves of received antenna current at 10.45 a.m. and 5 p.m. have been plotted in Figs. 8 and 9, it is noticeable that there is no evidence of a sunset effect, the signal strength at 10.45 a.m. being the same as that at 5 p.m. on the shortest day, when the time of sunset here is 3.49 p.m., and the 5 p.m. signal is, therefore, over one hour after the time of sunset.

* A. E. Kennelly. *Proceedings of the Institute of Radio Engineers, loc. cit.*

[illegible]

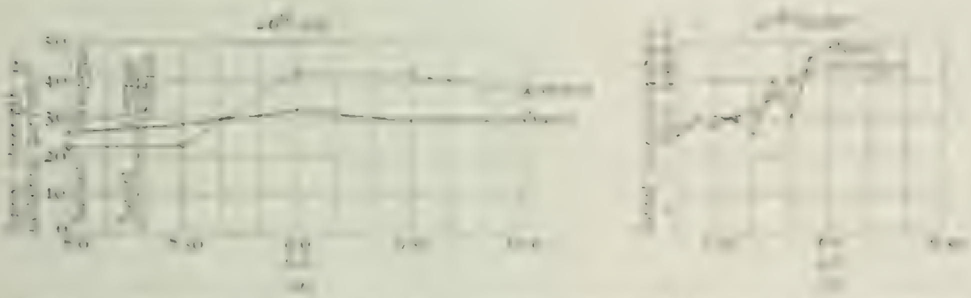

FIG. [illegible]—Special Signals emitted from Paris. Comparison between Variation in Signal Strength at Sunset at Nancy and Liverpool.

tests have also shown, the variations during a single night may be very large, and the difference in the ratio from day [illegible] It is interesting to notice that the greatest ratio observed between night and day strength occurred in July 1913. [illegible]

A possible explanation of the observed phenomena may be as follows: When the atmospheric conditions are bad and rain has fallen, the transmission is good and the effect [illegible] upper regions of the atmosphere, [illegible]gular increases in the received antenna current, such as are observed in the all-night tests referred to later on, are prominent, because of the transparency of the lower atmosphere to the waves. On the other hand, [illegible] [illegible]nals, owing to the [illegible]

reflection and refraction at the shadow band. The theory of cloud reflection, however, may easily be applied to [illegible] places.

If the atmospheric conditions between Paris and Nancy were good, *i.e.* if the sky were cloudy and rain had fallen the signal strength would be good and no increase would be observed at sunset. If conditions between Paris and [illegible] a clear sky, the fall of darkness would give rise to the [illegible]

[illegible] by Mosler on the variation in the ratio

[illegible]

of night to day strength with time of year are of great interest, but it does not seem possible to get a definite ratio between night and day strength which will hold for any day in any given month. The variations between one day and another in the same month are very great as is shown by the curves for 11 October and 26 October. It is to be hoped that it may be possible to examine the sunset effect much more completely than has been interesting to notice that signals received at 5 p.m. do not show any increase above those at 10.40 a.m. on the shortest day of the year, and throughout the months of December and January. There is, in fact, throughout the year very little difference between the morning and evening signals, certainly none greater than that due to more or less irregular variations in the morning signals. Mosler found that there was a maximum ratio of night

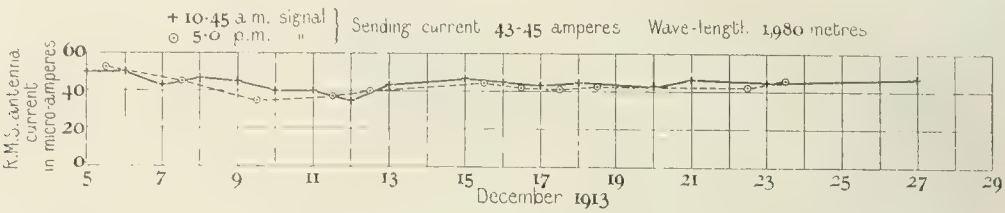

FIG. 8.—Curve showing Variation in Antenna Current received for 10.45 a.m. and 5 p.m. Signals from Paris during December 1913.

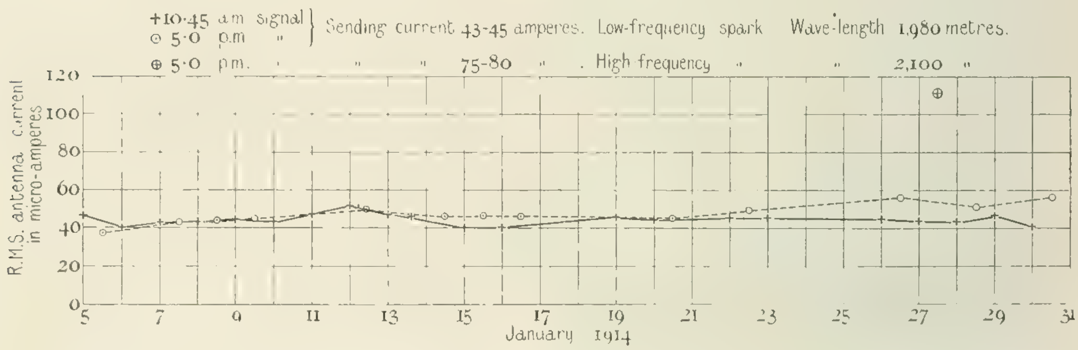

FIG. 9.—Curve showing Variation in Antenna Current received for 10.45 a.m. and 5 p.m. Signals from Paris during January 1914.

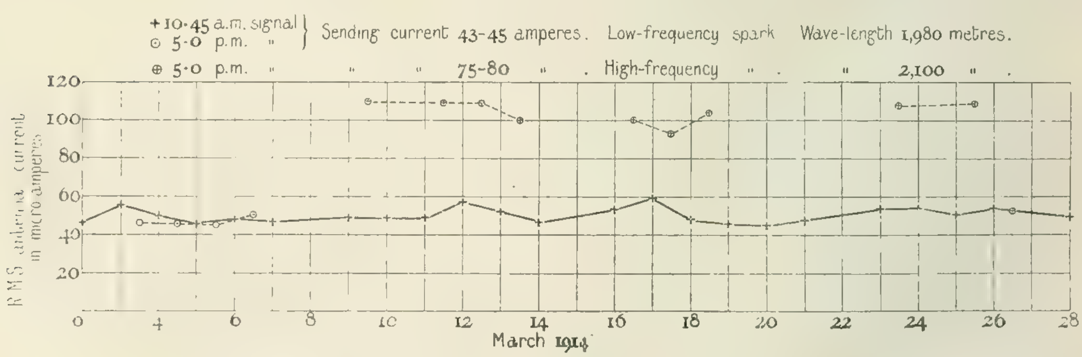

FIG. 10.—Curve showing Variation in Antenna Current received for 10.45 a.m. and 5 p.m. Signals from Paris during March 1914.

possible up to the present. This could be easily done if a series of long dashes were sent out from some powerful station at the time of sunset for every day in the year, and arrangements made to measure the strength of the signals received, in as many different observing stations as possible and under all kinds of atmospheric conditions.

Comparison between morning and evening signals.—In connection with observations at 10.45 a.m. and 5 p.m. which have been plotted in Figs. 8, 9, and 10, it is and day strength in November and April, not in December as might perhaps have been expected, the ratio in December being 1·79 against 3·15 in November and 2·2 in April. Mosler's results may be taken as giving some evidence that the maximum night strength condition tends to occur either earlier or later in January than it does in November or April. In view, however, of the fact that the variation during the night is so great, it is very difficult to base theories on Mosler's results. It was found in these tests, for example, that on 23 February

[illegible]

cannot, in other words, produce much effect until the [illegible] of sunlight makes it sufficiently transparent to enable the [illegible]

[illegible] that it is possible that the real factor in very long distance transmissions is the influence of earth or surface waves. In this connection it may be pointed out that between [illegible]

The fact that the night strength is so variable, however, [illegible] occurs after some more or less definite interval from sunset, seems to show that the earth transmission theory cannot be a complete explanation of the facts. It seems evident that in looking for the explanation of variation [illegible] must have recourse to changes in the [illegible] than in the surface over which [illegible]

[illegible] gnal strength or (antenna current)* is plotted [illegible] of the weather conditions at the two places [illegible] gham † that there was a marked fall in signal strength when heavy rain fell in Paris, and it [illegible] the constancy of the antenna [illegible] support this view.

[illegible] insulated aerial rain should carry away some of the charge

[illegible]

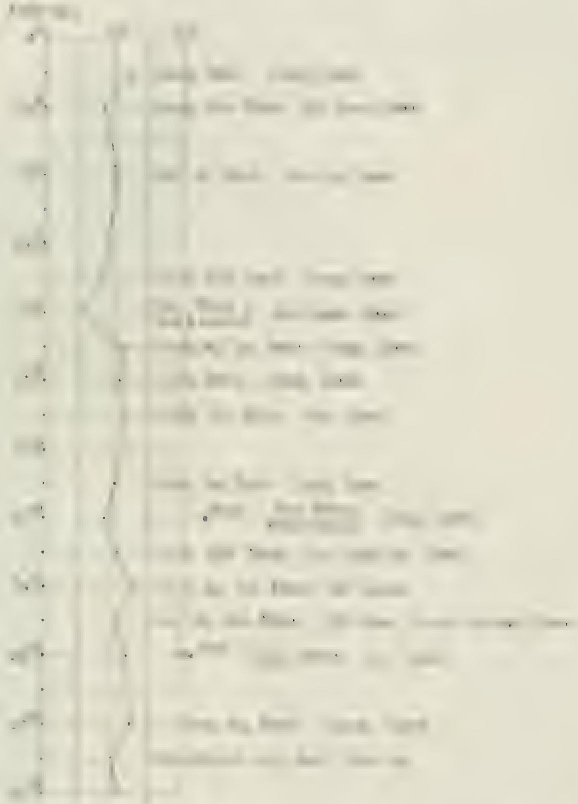

FIG. 11.—[illegible]

not conclusive on this point, as on several other days in the year when it was raining in Paris the signal received [illegible]

[illegible] show that bright sunshine is not [illegible] operators, who have stated that during a [illegible] sunny weather their range appears to be very much restricted (this may possibly be due to large earth [illegible]

[illegible] differences in signal strength from day to day but as the station is in an experimental state it is hardly possible to base accurate comparisons upon them.

[illegible]

being an actual diminution in the strength of the night signal as compared with the day. This minimum, however, corresponds with heavy rain in Paris; it is possible that the minimum may have been due to defective insulation of the Paris aerial. This is not likely, for the reasons just given. At midnight, for example, the antenna current used for the three long dashes sent out, was 44, 45, 45 amperes. The sending antenna current when the day strength (about 3 micro-amperes) just after sunrise at 4.33 a.m. In this case also there was heavy rain just before 10 p.m., and this would correspond with the same atmospheric condition as occurred during the Paris all-night test.

It would seem from these results, therefore, that one of the causes of change in signal strength at night is rain. After the fall of rain the atmosphere becomes more

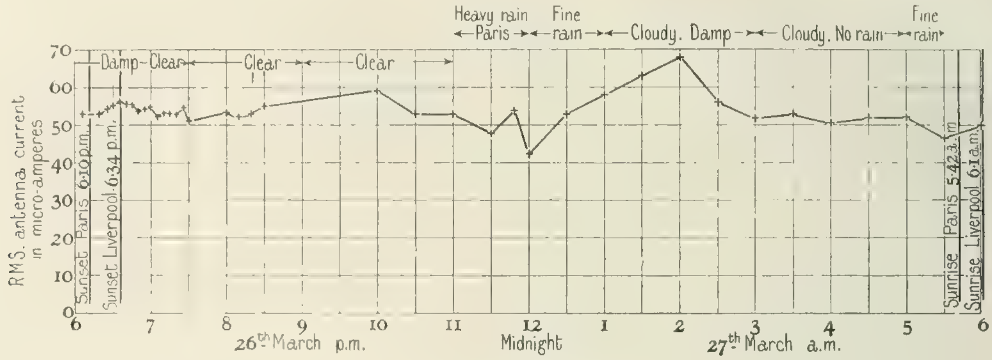

FIG. 12.—26 March, 1914. 6 p.m.—27 March. 6 a.m. 12-hour Test. Paris Antenna Current, 43–45 amperes.

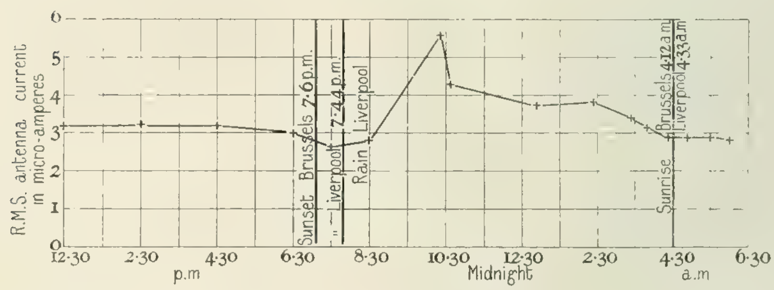

FIG. 13.—4 May, 1914. Brussels 24-hour Test.

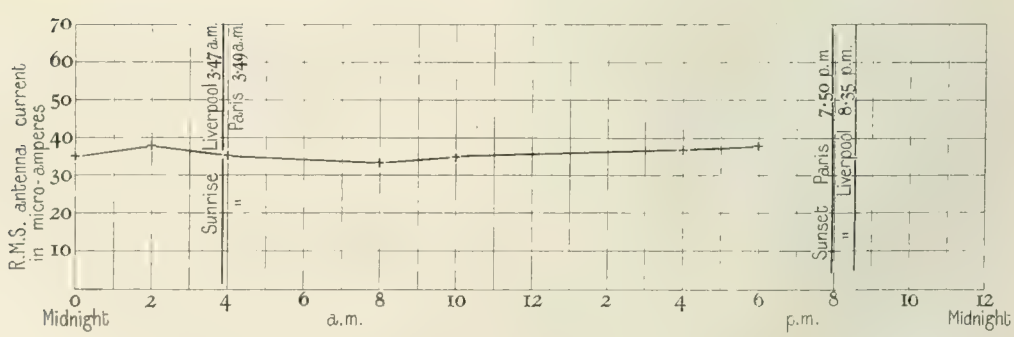

FIG. 14.—Paris. 8 June, 1914. Midnight to 6 p.m. Paris Antenna Current, 43–45 amperes.

sky was clear, say at 7.20 p.m., was 44, 45, 44 amperes. Two hours after the rain had ceased, the antenna current received rose from 52 to 68 micro-amperes. The same thing occurred in an all-night test which was made in connection with the Goldschmidt stations at Brussels. In that case the antenna current received at 10.35 p.m. suddenly increased to 5·5 micro-amperes, about twice what it had been at 8.30 p.m., at 10.45 p.m. it had fallen, and then diminished still further, until at midnight and 2.30 a.m. it was only 3·9 micro-amperes, falling to normal transparent for the electric waves and allows the reflections already referred to, which cause an increase in the strength of signals, to become more marked; that this is possible is evident from the fact that a fall of rain must tend to de-ionize the air and carry down the charged nuclei on which rain-drops form, and which make the air conducting and therefore absorbent.

It is interesting to notice that in the plates giving records of the signals taken during the all-night run from Paris there is a very considerable variation in the strength of the

[illegible]

varies within comparatively narrow limits, but the average [illegible] less than that during December and January. This is not in accordance with the results obtained by Mosler, and it is possible that the difference in the figures may be due to the fact that the transmission in this case is partly over sea.

The variations in strength of signal from day to day are comparatively slight, but they are noticeably greater for March and July (Figs. 10 and 11) than they are for [illegible]

[illegible]

(1) [illegible]

(2) That the ratio between the night and day strength varies with the time of the year, and also from day to day in any given month, as shown by Mosler.

(3) That on a fine clear day the "sunset effect" occurs [illegible] varies with the weather conditions. When rainy [illegible]

(4) [illegible]

[illegible]

[illegible] signals to enable the investigations of sunset effect and night variations to be made, to Mr. F. [illegible] Bidston Observatory who has provided the times of sunset and sunrise on the days when special tests were made, [illegible]

APPENDIX I.

[illegible]

[illegible] whatever arrangement of circuit is adopted to tune the aerial.

[illegible]

Since the current i_2 through the detector circuit is pro- [illegible] is a constant.

[illegible]

If circuit (3) is excited by a buzzer, the electromotive force in circuit (2) $= M' \omega i_b$, where i_b is the current in the buzzer circuit and M′ is the mutual induction coefficient between circuits (2) and (3).

The volts on condenser $(C_2) = \frac{M' i_b}{R_2' C_2'}$ (the circuits being tuned), where C_2' is the condenser capacity for tuned conditions and R_2' is the resistance of secondary circuit (2).

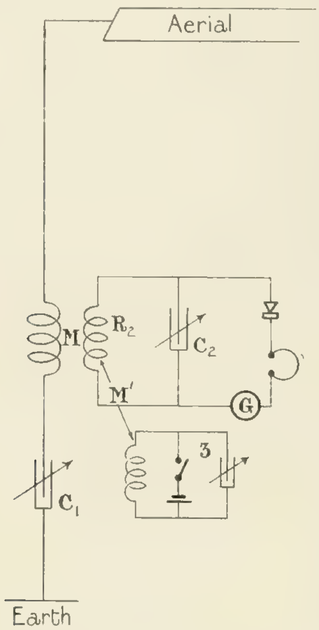

Fig. 15.

Since, as before, the current through detector circuit, i_d', is proportional to (volts on condenser)^2, $\sqrt{i_d'} = K \frac{M' i_b}{R_2' C_2'}$.

Hence $$\sqrt{\frac{i_d}{i_d'}} = \frac{M i_1 R_2' C_2'}{M' i_b R_2 C_2}$$

therefore $$i_1 = \sqrt{\frac{i_d}{i_d'}} \frac{M' R_2 C_2}{M R_2' C_2'} i_b.$$

If R_2 and R_2' are the same, and C_2 and C_2' are the same, *i.e.* if the secondary circuit is tested on the same wave-length as that on which it is to be used, then

$$i_1 = \sqrt{\frac{i_d}{i_d'}} \frac{M'}{M} i_b.$$

Hence the antenna current can be found in terms of i_b.

APPENDIX II.

Method of Estimating Current in "Buzzer" Circuit.

The current in the buzzer circuit is measured by an inductively-coupled circuit connected in series with a thermo-ammeter and resistance (see Fig. 16).

Let i_b be the current in buzzer circuit, M_o the mutual inductance between measuring coil and buzzer coil, then

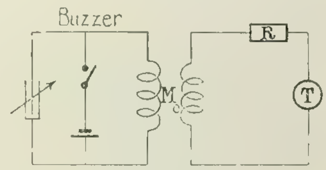

Fig. 16.

the electromotive force in the measuring circuit $= M_o \omega i_b$.

Since the resistance of the circuit is very large compared with its reactance, the current in the measuring circuit $i_t = \frac{M_o \omega i_b}{R_t}$, where R_t is the total resistance in the measuring circuit.

Hence $i_b = \frac{R_t}{M_o \omega} i_t$, and i_b may be found from the thermo-ammeter reading.

Discussion before The Institution, 11 February, 1915.

Mr. Duddell

Mr. W. Duddell: This paper raises many important questions as regards both the measurement of wireless signals and their propagation through the atmosphere. I propose to confine my remarks to-night to the problems of measurement because I feel that the number of results that have accumulated is not anything like large enough at present to enable us to form any real theory as to the propagation of the signals. I have felt for some time that we want a complete and systematic investigation over a very wide area of a definite set of signals sent out from a single station, so that we may be able to compare the results in all directions and make comparisons over a length of time in order to study the propagation. Some members may remember that an attempt was made in Brussels by Mr. Goldschmidt to form an organization, and that he actually got together many representative wireless experts from different countries with a view to carrying out this work. The Institution formed a committee to co-operate in this country. Last Easter we were all together in Brussels as a friendly group of workers, starting on the first piece of serious work that was contemplated, namely measurements in connection with the eclipse of the sun. Unfortunately events have since occurred which have prevented any of that work being carried out. The programme for making the measurements then discussed showed us how very difficult it was to be certain that the conditions in each case remained the same. The difficulty was to ensure that the conditions of the earth, of the aerial, and of all the circuits remained constant. One might think that the number of watts being received was changing, whereas it might really be the conditions of one's own circuits. The author has gone a good way towards getting over that difficulty by using a local calibrating circuit in which he can keep the amount of energy radiated constant and can let it react through a fixed mutual-induction on the measuring circuit. The proposal made at Brussels was to go

Mr. D

[illegible] side vertical on the galvanometer spindle, and by means of an optical system with a cylindrical lens endeavoured to get [illegible] of 100 to 120 millimetres per micro-ampere with a periodic [illegible] able to get in Arlington, near Washington, deflections due [illegible] been able to compare the difference of longitude between [illegible] 30 millimetres were obtained in Arlington from the Paris [illegible] at any rate of being able to get sufficient sensibility with another type of instrument. I have attempted to build [illegible] received here in London on a very small aerial. [illegible]

[illegible] strength of signals at Glace Bay coincides with the [illegible] any definite conclusion as to what is [illegible] variation until, as Mr. Duddell suggested, [illegible] Until [illegible]

[illegible] coping with its variable sensitiveness will be very useful [illegible] propose to go into the rather voluminous theories that [illegible]

Dr. Eccles. across the North Pacific find that with a 2 kw. ship-station the operators can often transmit 2,000 miles, and are expected regularly to receive from 5 kw. land-stations over at least 2,000 miles by night. It is not a matter of freak communication; it is a matter of regular communication. Freak signalling extends to 3,000 miles, even in summer. I have myself heard signals from a 5 kw. station at 2,500 miles in summer, and in winter the operators say they can get signals at such distances as 3,500 miles. I was at one station in Samoa last summer where they could hear small ship sets off the coast of Alaska, off the coast of Mexico, and not very far from the coast of Chili. Those are very big distances over which to hear such small ships. If those figures are compared with the figures obtained by the same plant in the daytime, namely about 200 miles, the comparison is very striking. That is a ratio of 10 to 1 in distance, and if we believe in an approximate inverse-square law we should say that at a fixed laboratory, like the author's, one ought to get a ratio, in energy, of something like 100 between day and night signal strengths from a fixed station. Now the author's ratio, in current, is 3, and in energy 9 or 10, so that he is only getting one-tenth of the variation that is expected from ordinary working in the Pacific. I supppose one reason for that is that the distances between Paris and Liverpool and between Brussels and Liverpool are what might be called small compared with these other distances, and on that account the uppermost levels of the atmosphere probably have little effect, whereas in the case of very long distances they probably play an important part. One point that has been raised in the paper is the effect of rain in Paris on the strength of signals received at Liverpool. Mr. Vyvyan has pointed out that from experiments made at Letterfrack, quite close to Clifden, and at Glace Bay, 2,000 miles from Clifden, they suspect that on certain occasions local circumstances at Clifden are the cause of variation in the signals. If we have an antenna like that at Paris, and we write down the electrical equations for the steel tower placed near that antenna and assume an insulation resistance of infinity between the top of the antenna and the top of the tower; and if we assume that the rain wets the insulators and reduces the insulation resistance from infinity to, say, 1 megohm, we find that the damping produced in the signals emitted may become between 10 and 70 per cent greater. That is obtained without the least perceptible change in the antenna current. Besides this the wetting of the ground will alter the intensity and distribution of the ground currents and so increase the damping. When, however, the damping of the signals emitted is changed, the strength of the current induced in the receiving antenna is altered very considerably. I find that occasionally anthing like 20 or 30 per cent variation in the signals received can be expected through such a change in insulation resistance as I have mentioned, merely through variation of the damping.

Mr. Taylor. Mr. J. E. TAYLOR: Unlike Mr. Duddell, I propose to confine my remarks almost entirely to the theoretical side of this subject. We have been given a considerable number of detailed observations and a certain amount of experience, and that must be my justification for considering the theory at this stage. I appreciate to the full the painstaking and thorough manner in which the author has carried out the observations detailed in this paper, which doubtless constitute but a small part of the total work that he has done in the matter, but I think it will be agreed that the point of prime importance is to arrive at a satisfactory explanation of why these variations occur, in order that we may know how to cope with them and how to avoid them, if necessary, or to alleviate them. I regard as very valuable the opportunity which this paper affords for discussing possible solutions. My faith in any of the speculative theories which have up to the present been put forward is very frail, and of all the irresponsible theories that of a heavily-ionized upper atmosphere is the one which I think has claimed the most offenders. I fail to see that there is any justification in fact for the assumption that the upper regions of the atmosphere can possess a conductivity approaching the value which is necessary either for reflection or for guidance of waves. The conductivity assumed has been compared with that of sea-water. I believe what has given rise to that comparison is some of Sir J. J. Thomson's experiments. Those experiments might equally well be cited as proving high conductivity for air at ordinary atmospheric pressure. We have only got to use a wire circuit with a spark-gap interpolated in it in order to prove that the whole circuit has a high conductivity, including the air in the spark-gap, if the stresses impressed on the circuit are sufficient to cause rupture in the spark-gap. By using rarefied air it is possible to make that circuit all spark-gap and no wire. What bearing that has upon proving the high conductivity of rarefied atmosphere I cannot say. I shall base my main criticism of the paper on the dictum that the author gives, that calculations strongly support this theory of an ionized layer. There may, however, be other explanations and other solutions. One objection that I raise to the theory as it stands is that it is necessary to suppose there are banks of highly-ionized air which act as reflectors, and that they vary in form from time to time and so produce variations in signals. For long waves to produce any appreciable reflection they must be of huge size and not too irregular in their lower surfaces. I think it is not very feasible that these huge banks of ionized air can vary with sufficient rapidity to produce the variations that are observed. I do not like to condemn a theory too strongly unless I can put forward another possible solution, and I would suggest the following as at least indicating a likely direction of enquiry. To make an oscillating circuit radiate strongly it is necessary that it shall produce a well-distributed electric field; and as the conductor of an oscillator is opened out so as to increase the spread of the electric field the radiating power increases. The prime function of the antenna of a wireless transmitter is to produce this spread or distributed field. If we take into consideration the fact that in the atmosphere there is normally a very considerable electric field due to the normal potential gradient of the atmosphere, then it will be clear that the exposed antenna of a wireless station has an appreciable field due to this atmospheric gradient located upon it; that is to say, the antenna has superposed upon the field due to the excitation of the antenna another field due to the atmospheric gradient. That superposition of the atmospheric potential gradient has in effect the property of greatly increasing the spread of the electric field from the antenna in an upward direction. This field is essentially a vertical one; and I submit the result of that will be that

[illegible]

(Communicated): It will be evident also that on this theory the magnitude of variation of signals should be very [illegible]

[illegible] for long-distance stations, especially in tropical regions. [illegible] there are other ways of regarding the solution that I have [illegible] of the oscillating system. These charges cannot, of course, neutralize themselves through the oscillating system, but the electric field nevertheless links them up to the [illegible]

[illegible] distant stations with intervening land, and from stations at [illegible]

[illegible] interested in the paper from the instrument point of view. [illegible]

Mr. Swinton. oscillations not necessarily rectified. The difficulty is that all such instruments are comparatively insensitive. The instruments that work with rectified currents, such as the ordinary telephone, the Einthoven galvanometer, and Mr. Abraham's galvanometer to which Mr. Duddell referred, are incredibly sensitive. I think the Einthoven galvanometer will give readable signals with something like one-billionth of a watt, which is an extraordinary small amount of power. Some idea of the smallness of this fraction will be seen from the fact that it is of something like the same order as 1 second of time is to over three thousand years. Unfortunately all the other methods are comparatively insensitive. There is the thermal method that Mr. Duddell has used, but I suppose we must look upon all these thermal instruments as heat-engines. They depend on that third law of thermodynamics which makes all heat engines very inefficient, and that is specially so when the heat limits are so exceedingly small as they must be in these cases. Nobody could confer a greater benefit upon this comparatively new science than by discovering some instrument that would measure accurately these oscillations without it being necessary to rectify them. I am rather astonished that one of the Marconi magnetic detectors was not tried. It is, I believe, not quite so sensitive as the crystal detector, but in the nature of things it must be much less liable to alteration in sensitiveness.

Mr. Coursey. Mr. P. R. COURSEY: With reference to the connections shown in the first diagram given by Professor Fleming in his communicated remarks, the main trouble that we experienced was the direct influence of the buzzer contact spark on the receiving coils and detector. I should like to ask the author if he ever had any trouble of that nature, because we found the effect so considerable that it was necessary to put the coupling coils, together with the buzzer generating the oscillations, as far away as possible, and to connect them to the receiving apparatus by concentric leads with the outside conductor earthed; while for the same reason the buzzer was driven from an alternator instead of from the usual battery. The group frequency of the oscillations generated by the buzzer was adjusted to be the same as that of the signals being received, as the sensitiveness of the detector was found to vary not only with the oscillation frequency, as mentioned on page 332 of the paper, but also with the group or spark frequency. There is one other matter that I should like to mention as to the relative advantages of the visual and photographic methods of using the Einthoven galvanometer. With the calibration arrangements employed in these tests at University College, London, it seems to me that the direct visual method is much to be preferred, as then the effects of the variable sensitiveness of the Einthoven galvanometer can be practically eliminated, since it is used merely as an indicator, by taking a deflection on the received signals and then immediately changing over the complete receiving apparatus to the artificial antenna, or calibrating circuit, and adjusting the coupling coils to imitate exactly the previous deflection. Once the coupling coils have been calibrated, the number of micro-amperes in the antenna can then be read off from a curve. It is interesting to note that the average strength of the currents received during the daytime on the 10.45 a.m. signals, as given in several of the curves in the paper (*e.g.* Figs. 9 and 10) is about 40 micro-amperes, whereas when the high-frequency spark was employed at Paris (5.0 p.m. signals) the received current was somewhere between 100 and 110 micro-amperes. We obtained in London practically the same figures: the daily strength for the 10.45 a.m. signals varied between about 30 and 50 micro-amperes, while in the readings that we also took in the latter part of last July on the 5.0 p.m. signals sent with the high-frequency spark, the figures were of the order of 100 micro-amperes. Although this is purely a coincidence on account of the sizes of aerials employed, yet the agreement in the ratio of strengths of low-frequency to high-frequency spark signals is a confirmation of the fact that the two methods of calibration must at all events be giving fairly accurate and comparable results.

Professor Howe. Professor G. W. O. HOWE: All who have done any work of the nature described in the paper know the difficulties that are inherent in connection with it. All high-frequency work abounds in pitfalls, and when one thinks one has arrived at a particular result one often finds that it is altered to something quite different when one allows for a factor that has been neglected, such as some electrostatic effect. I also made at the same time as the author measurements of the signals sent out from Brussels and from the Eiffel Tower, but I was working with a different object and using another method. My object was to do away with all such things as crystal detectors and to get some absolute measurement of the electromagnetic field produced in London by the Eiffel Tower signals. I removed everything that introduced any doubt; I simply coupled a thermal galvanometer to the antenna and measured the actual current produced in the antenna by the electric field; then from the high-frequency resistance of the antenna and earth, and the current set up in it, it was possible to calculate the electric field on certain assumptions. Even that is a very difficult thing to do, because we do not know what height to assume for the receiving aerial, especially in the neighbourhood of buildings and where the aerial is of a peculiar shape. We want a simple standard aerial for the purpose, and it ought to be removed from any buildings. The difficulty in this method is that we require a long dash to be sent from the Eiffel Tower and Brussels stations, because the thermal galvanometer takes a few seconds to attain its steady reading. A dash is not much good for the purpose unless it lasts about 10 seconds so that we can take the reading, and then, while we are reading it, we are quite at the mercy of every atmospheric and every other station that is sending. Another difficulty is that, even if we "listen in" to see that our signals are pure, we are little better off, because the arrangement with the thermal galvanometer is a very unselective arrangement. One only has the antenna with a thermal galvanometer inserted, which is equivalent to a considerable resistance added to that of the antenna. Sharp tuning is thus impossible, and the antenna picks up all signals of any wave-length. There are thus great difficulties in carrying out measurements by this ideal method, and I can quite see the great advantage of using an Einthoven galvanometer and crystal detector, as the author has done, to see actually what one is getting, so that one can pick out the desired signals. The author has referred to Lutze's experiments with balloons. I do not know whether Lutze found that this double layer of

[illegible] Mr. Taylor's remarks, because we are now getting such a variety of ideas on the subject of the ionization of the [illegible] thing in that way by making suitable assumptions. We [illegible] less absorbing; we have stray ionized clouds affecting the [illegible] the sunlight, or persist night and day, and which will either reflect or refract or scatter the waves; and we have now, as if these were not sufficient, alternate layers of moist and dry air. It is refreshing therefore to hear that Mr. Taylor proposes to blow away all these clouds, ionized [illegible] of the gradient of the earth in affecting the transmission. It may account for some of the phenomena, but it is difficult to believe that it can account for all the wonderful [illegible]

[illegible] J. A. Fleming [illegible]. This paper has considerable interest for me, because in the early part [illegible] co-operate with him, in order that we might find out if the [illegible] us all [illegible] :—The signals were received on an Einthoven galvanometer through the usual [illegible]

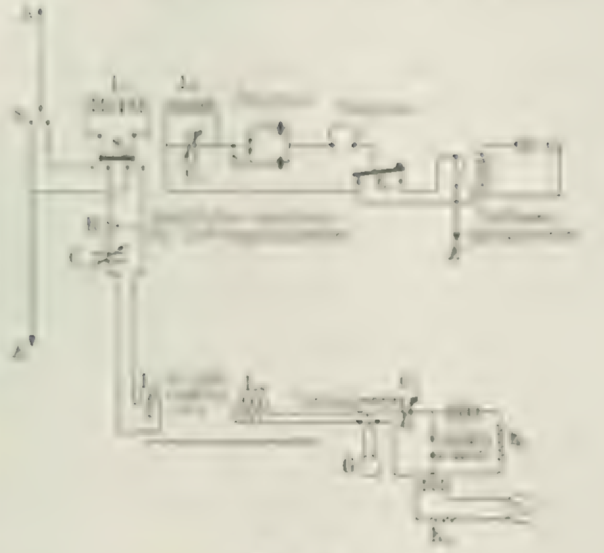

Fig. A.

[illegible] repeat the deflections of the Einthoven galvanometer produced by the Paris signals by a known current in an [illegible]

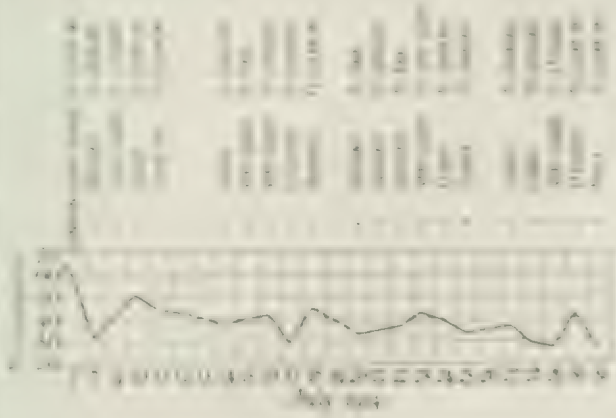

Fig. B.

the diagram of connections. The [illegible] method were carried out for me by [illegible] and the results were plotted in diagrams. We operated on [illegible] weather report [illegible] of the weather [illegible] by the [illegible] observations were terminated by the o[illegible]

It will be seen from Fig. B that we have in this monthly chart an example of the same curious variations in signal strength as shown in the author's Fig. 11. In our chart it appears as if the greatest falling off in the signal strength occurs when the sky is overclouded both in Paris and in London, but I do not think that any generalization can be drawn from charts of this kind extending over only a short period of time. Before we can draw any valid conclusions it would be necessary to have an antenna set up near to Paris and an automatic record kept of any variations in signal strength occurring close to the sending station; moreover, such an antenna ought to be in duplicate, one antenna being earthed and the other non-earthed. In the observations so far taken by the author and by me there is nothing to show definitely whether these variations in signal strength are due to something happening at Paris, or in London or Liverpool, or in the region between. If the author and I had been able to work simultaneously on the same signals from Paris, and if the variations in signal strength had been found to occur simultaneously in Liverpool and London over a considerable period of time, then we should have one useful fact to go upon. I cannot believe that in such a short distance as 200 miles the large variations in signal strength which we have observed in London are entirely due to the ionization of the air. I have already several times expressed the opinion that in such short-distance transmission there is a considerable degree of propagation through and over the earth's crust, and that the reception is not entirely due to a true space wave. It is much to be regretted that this calamitous world war has put a stop entirely to wireless investigation, but it is to be hoped that at a no great interval of time it may be possible to resume it. Until we get more facts and can digest them more completely, discussions as to the theory of them must necessarily be very imperfect. In the discussion which took place on this subject at the meeting of the British Association at Dundee, two years or more ago, I suggested the establishment of a British Association Committee for radiotelegraphic investigation, and that committee was duly appointed, with Sir Oliver Lodge as chairman. Under the direction of Dr. Eccles, its secretary, much valuable work began to be organized, which was also interrupted by the war, but in due time that work will reap its reward by furnishing us with more material for the discussion of the interesting questions which have been dealt with in this paper.

Professor Marchant.

Professor E. W. Marchant (*in reply*): I entirely agree with Mr. Duddell's criticism: that the number of results obtained is insufficient to establish any real theory. The paper is only a beginning; it was intended, more than anything else, to stimulate accurate observation of signal strength, because I think it is only when we have obtained a large number of observations that we can possibly hope to arrive at any satisfactory theory. I put forward my theory more as a hypothesis for eliciting criticism and stimulating discussion than as a conclusive explanation of the variations in the strength of wireless signals. It was intended for criticism, and I think the criticism of it has not been such as to prove the theory of ionized clouds untenable. I hope that the International Commission over which Mr. Duddell presided at Brussels last April may have many meetings in the future when conditions are more favourable, and that such a programme as he has outlined may be carried to a successful issue. Mr. Duddell suggested that it would be better to calibrate on the aerial. The difficulty that I have found in calibrating on the aerial is that interference is very likely to occur from outside sources, and should it be a bad day and a lot of atmospherics come in, it is extremely difficult to calibrate if one tries to do so on the aerial circuit. Moreover, when using crystal detectors it is often necessary to calibrate while signals are coming in, and this cannot be done if the aerial is in circuit. If one can do so, it would seem to be very much better to calibrate on the aerial than on the secondary, but the practical difficulties are greater. Mr. Duddell's description of Professor Abraham's instrument was very interesting. I did not intend to suggest that the Einthoven galvanometer is the only instrument possible, but it is certainly one of the best that we can get at the present time. Possibly Professor Abraham's instrument may be even better later on.

I was exceedingly interested in Mr. Vyvyan's account of the experiments at Letterfrack and Clifden. It is remarkable that the signals from Clifden to Letterfrack should show the same kind of variations as those between Clifden and Glace Bay. If that is the case, it renders nugatory the theories that have been advanced to explain the variations observed during the day in the transatlantic transmission of wireless signals. The distance that I mentioned of 1,200 miles for a 1·5 kw. set is very small compared with those mentioned by Mr. Vyvyan. The Pacific is certainly a wonderful place for long-distance transmission, evidently much better than the Atlantic. I quoted the 1,200-mile transmission because it had actually come within my own notice. His observations that the effects obtained are due, to a very large extent, to local conditions are entirely in accordance with the conclusions that I have arrived at from our observations.

Dr. Eccles gave some very interesting figures in reference to the long distances that can be covered at night in the Pacific. I think, however, that they have not been observed anywhere else than in the Pacific; certainly we have never got anything of that sort here. I think, however, that distance records are not to be compared with energy records over a fixed distance, because all sorts of reflection effects come in, reflection from the upper atmosphere and so on, which must vary enormously at different distances, whereas with fixed distance at least one possible variable is constant. I was interested in Dr. Eccles' calculations on the effect of defective insulation resistance. The defective insulation would certainly be shown by an alteration in the decrement of the sparks. In future tests it is our intention to record the decrement of every signal as well as its strength. This can easily be done when a photographic record is taken on the Einthoven galvanometer.

With regard to Mr. Taylor's theory that the increase in signal strength at night is due to what I understand to be an artificial heightening of the aerial owing to the effect of atmospheric electricity, it seems to me to be really an extension of the ionized-cloud theory, only Mr. Taylor assumes that the clouds which affect the transmission are all above the aerial. The theory is of great interest, and one which should be capable of experimental test with balloons. With reference to his criticism that ionized

[illegible]

[illegible] experiments that [illegible] their being abandoned. [illegible] his theory is not inconsistent with the [illegible]

[illegible] in strength should have been [illegible]

[illegible] making a comparison. I think such observations would [illegible]

[illegible] what has been said already by Mr. [illegible]

MANCHESTER LOCAL SECTION, 9 FEBRUARY, 1915.

Mr. B. HOYLE : I have only a few questions to ask. One [illegible] through it. . . ." Carborundum crystals are known to [illegible] whilst perikon and [illegible] them to pass a very constant continuous current for a [illegible] For the same setting I found that the same continuous current was yielded, using an alternating-current [illegible]

[illegible] Manchester to see where the change occurred, and with this particular pair that the author has been using, namely [illegible]

Mr. Hoyle. thermal when used without an auxiliary voltage (Fig. 1). I should like to ask the author about the constancy of the resistance of this crystal pair. On page 331 the effective resistance of the crystals is mentioned as being about 32 ohms. In the majority of cases these crystals vary very much. I have found an average of 18 to 20 ohms for perikon. I do not know whether 32 ohms is a very high value for the resistance of the crystal or not. I am not able to discuss the measurement of the actual signal strength, because, as the author points out, the only way to measure the strength is to use an Einthoven galvanometer, and unfortunately we have not one at the Technical School in Manchester. I think we are all hoping to open up communication again with Liverpool. In Manchester I have listened interestedly to the special experimental signals being sent from Paris, knowing that Professor Marchant is photographing the results.

Professor Marchant. Professor E. W. MARCHANT (*in reply*): I was very interested to hear what Mr. Hoyle said about crystal sensitiveness. I put in the statement, that the sensitiveness of the crystal might vary with frequency, as a disclaimer, because I had not made any observations myself on the effect of frequency on sensitiveness in the crystal combination that I used. Therefore, I am interested to know that he finds the sensitiveness is constant. That is borne out by a paper read by Lutze in Brussels last April before the International Scientific Radio-Telegraphic Commission. He had made a great many tests with high frequencies, and obtained nearly the same sensitiveness as he found at a frequency of about 100. The crystal which was good on low frequencies was good also on high frequencies. At the same time, of course, the question of the effect of frequency on sensitiveness does not affect these tests.

With regard to the thermal action of the crystal detector, I was interested to know at what values of current in the circuit Mr. Hoyle had found the thermal action changed into valve action. We were evidently well below the limit of valve action, because the currents that we used in our crystal circuits were never more than 0·5 micro-ampere. Of course the antenna currents received are larger than that.

As regards the constancy of the effective resistance of the crystal, I did not make a great number of tests on that point. I tried it once or twice and it was usually about 30. The figure 32 was a little uncertain because it was obtained by difference, *i.e.* the difference between the resistance measured by a half-deflection method and that calculated from the dimensions of the wire in the coils. The estimated resistance of the coils, allowing for skin effect, is not quite exact for circular coils, as has been shown by Dr. Howe, and the estimate of effective crystal resistance is only to be regarded as an approximation.

INSTITUTION ANNOUNCEMENTS.

MEETING OF 25 MARCH, 1915.

At the Ordinary Meeting of the Institution on the 25th March the following paper will be read and discussed :—

W. L. PREECE. "Telephone Troubles in the Tropics."

SCIENCE ABSTRACTS.

The Council wish to draw the attention of members to the advisability of subscribing to *Science Abstracts*, a publication which cannot fail to be useful to all Engineers as a complete and concise record of current papers and work, and also as a work of reference. It is published in two sections, namely :—

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Section "B" (Electrical Engineering), containing abstracts from papers on General Electrical Engineering, Dynamos, Motors, Transformers, Electrical Distribution and Transmission, Electric Traction, Descriptions of Stations, Lamps, and Lighting, Storage Batteries, Electro-Chemical Processes, Telegraphy and Telephony, Radio-Telegraphy, Hydraulic Power, Steam Plant, Fuel, Gas and Oil Engines, Properties of Engineering Materials, Airships, and Aeroplanes.

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ACCESSIONS TO THE REFERENCE LIBRARY.

CANADA. DEPT. OF MINES, MINES BRANCH. Researches on cobalt and cobalt alloys, conducted at Queens University, Kingston, Ontario. pt. 1, Preparation of metallic cobalt by reduction of the oxide. By H. T. Kalmus [*and others*]. 8vo. 48 pp. *Ottawa*, 1913

ENGINEERING STANDARDS COMMITTEE. [Publications] no. 1, 47, 69 [no. 1, 47 revised]. folio. *London*, 1914–15

1, Lists of British standard rolled sections for structural purposes.
47, British standard specification of steel fishplates for bull head and flat bottom railway rails.
69, Report on British standard tungsten filament glow lamps (vacuum type) for automobiles.

KNOX, G. D. All about electricity. 8vo. 376 pp. *London* [1914]

PARLIAMENTARY PAPERS. HOME OFFICE. Mines and quarries : General report, with statistics for 1913. By the Chief Inspector of Mines. 2 pt. fol. *London*, 1914

1, Divisional statistics. 2, Labour.

SPON, E., and F. N., *publishers*. Spons' architects' and builders' pocket price book, 1915. Edited by C. Young and S. M. Brooks. 42nd ed. sm. 8vo. 310 pp. *London*, 1915

UNITED STATES : BUREAU OF STANDARDS. Annual report of the Director, Bureau of Standards, to the Secretary of Commerce for the year ended June 30, 1914. 8vo. 99 pp. *Washington*, 1914

DEPT. OF COMMERCE. Circular of the Bureau of Standards. no. 6. 5th ed. 8vo. 23 pp. *Washington*, 1913

6, Fees for electric, magnetic, and photometric testing.

HOW A TOP STANDS UP.

[illegible]

[illegible]

[illegible] The force of gravity [illegible]

[illegible] the frequency, and *vice versa*, of the bullets. [illegible] wheel has its bucket held still it returns [illegible] same velocity in the reverse direction.

[illegible] a rotating continuous [illegible] arm. In the diagram here- [illegible] at the lower end. This spins like a top [illegible]

[illegible] direction at right angles to the movement the top would [illegible]

[illegible] old courses, will tend to bend the arm of A up and the [illegible] duced by the top as a whole leaning a little towards the observer.

[illegible] a cone. The speed with which it describes it will depend [illegible]

[illegible] between lowest and the medium, or medium and highest positions, have partly translation movements at right [illegible]

[illegible]

[illegible]

the change of direction of the movement of A and B raises A and lowers B; and the arbor thus tends to move to the left. The arbor thus moves at right angles to the direction of the applied force. Helping the precession by external means thus raises the top to the vertical position.

The point "I" has been supposed to spin in the same place; but if the point is replaced by a small blunt nose it will roll to some extent on the table; and in the diagram it will roll so that the point moves away from the observer. That tends to make C fall and D rise, and to alter the directions of motion of A and B in such a way that A is raised and B depressed. The point "I" will therefore run round as the top precedes; and its movement will gradually raise the top to a vertical position so that it "sleeps."

The behaviour of gyrostats under various conditions can be followed by seeing which parts of the spinning body have their directions of movement altered, and tracing the forces so produced.

This simple explanation was published about 20 years ago in *Good Words*. As it is possible that some of the members of the Institution did not see the number, it seemed worth while to repeat it as it may help the understanding of Professor Gray's Kelvin Lecture.*

* Page 277.

REPRESENTATION OF THE TOTAL LOSSES IN IRON, DUE TO ALTERNATING MAGNETIZATION, BY AN EXPRESSION OF THE FORM $W = cB^n$.

By N. W. McLACHLAN, Associate Member.

(*Paper first received 7 December, and in final form 29 December, 1914.*)

The following experiments were carried out on different brands of iron by means of an Epstein tester used in conjunction with an alternator the wave-form* of which differed from a sine curve by less than 5 per cent. The object of the experiments was to ascertain whether the total number of watts lost per kilogram † could be expressed in the form $W = cB^n$, as an alternative to the usual expression $W = aB^{1\cdot6} + bB^2$ in which the hysteresis ‡ and eddy-current losses are considered separately. §

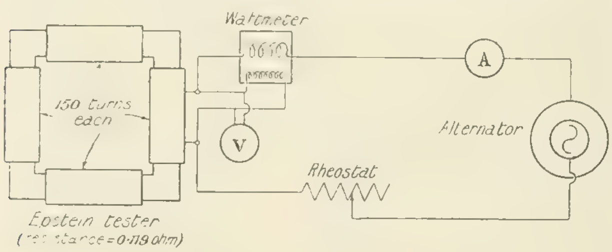


FIG. 1.

Fig. 1 shows diagrammatically the apparatus used in all the tests. In each case the supply frequency was kept constant and a series of readings of voltage-drop in the test coils (*i.e.* the back electromotive force), total number of watts lost (including I^2R and instrument losses which were deducted), and current, were taken. The voltage was adjusted so that the maximum flux density in the iron varied between 4,000 and 10,000 lines per square centimetre. Special care was exercised when readings were taken in the vicinity of these limits so that the values of a and b could be obtained as accurately as possible.

Table 1 shows the results obtained from a test of Stalloy (silicon iron) at a frequency of 50 periods per second. The particulars of the iron used are as follows:—

Number of iron cores ...	... =	4
,, plates per core	... =	46
Mean thickness of plate	... =	0·5 mm.
,, width ,,	... =	30 mm.
,, length ,,	... =	500 mm.
,, cross-section of core	... =	6·9 sq. cm.
Weight of each core ...	... =	2·5 kg.
Total weight of iron ...	... =	10 kg.

Fig. 2 shows, for various frequencies, the total iron loss in watts per kilogram plotted against the maximum flux density. In determining the values of a and b (hysteresis and eddy-current constants) the curves were drawn to a large scale and the values of W corresponding to $B_{max.} = 10{,}000$ and 4,000 were read off and substituted in the formulæ:—

$$b = \left(\frac{W_1 - 4\cdot33\,W_2}{0\cdot306}\right)10^{-8}, \quad a = \left(\frac{W_1 - 10^8\,b}{2\cdot512}\right)10^{-6}$$

The figures in Table 2 were obtained from the curve for Table 1 (shown in Fig. 2).

* Oscillograms of the E.M.F. wave-form were taken at the terminals of the Epstein tester for various frequencies. These showed that the wave-form differed from a sine curve by less than 5 per cent, whether the alternator was supplying power or not.

† Messrs. Mordey and Hansard observed that the total loss in iron plates often varied as $B^{1\cdot6}$. (W. M. MORDEY and A. G. HANSARD. Energy losses in magnetizing iron. *Report of the British Association for the Advancement of Science*, p. 697, 1904; and also *Electrician*, vol. 53, p. 790, 1904.)

‡ The Steinmetz hysteretic index 1·6 has been used. Mr. F. Stroude has shown that the indices for Stalloy and transformer iron are of the order of 1·66 and 1·7 respectively. (F. STROUDE. An accurate examination of the Steinmetz index for transformer iron, Stalloy, and cast iron. *Proceedings of the Physical Society of London*, vol. 24, p. 238, 1911–12; and also *Electrician*, vol. 69, p. 606, 1912.)

§ From a practical point of view it is the total loss which is required, as both losses are dissipated in heat eventually.

[illegible]

Hence the equation to the curve is

[illegible]

TABLE 3.

[illegible]

FIG. 2.

[illegible] brands of iron is the hysteresis constant [illegible] than the frequency.* This may be due to [illegible]

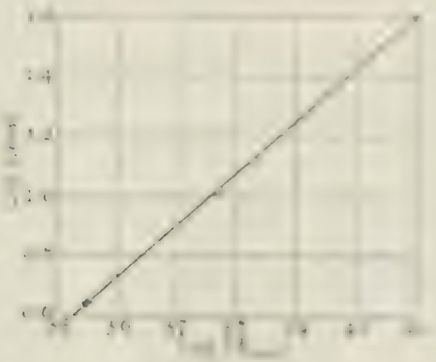


FIG. 3.

[illegible] that B_{max} is really greater than that given by calculation.

[illegible] effect.

[illegible]

different.* On plotting $\log n$ and $\log f$ it was found that the points were almost collinear, so that n and f are connected by a law of the form $n = c_1 f^{n_1}$.

TABLE 4. Stalloy (0·5 mm. thick).

f	f^2	n	$c \times 10^7$	$a \times 10^7$	$b \times 10^9$	$k = \frac{a}{b}$	$\frac{a}{f} \times 10^9$	$\frac{b}{f^2} \times 10^{12}$	kf
25	625	1·68	2·10	3·54	2·5	142	13·68	4·54	3,550
37	1,369	1·72	2·20	4·70	5·6	84	12·7	4·09	3,108
50	2,500	1·75	2·66	6·38	10·57	60	12·76	4·23	3,000
60	3,600	1·77	2·83	7·52	15·0	50	12·53	4·16	3,000

TABLE 5. Lohys (0·37 mm. thick).

f	f^2	n	$c \times 10^7$	$a \times 10^7$	$b \times 10^9$	$k = \frac{a}{b}$	$\frac{a}{f} \times 10^9$	$\frac{b}{f^2} \times 10^{12}$	kf
25	625	1·73	1·76	4·36	4·53	96	17·44	7·25	2,400
37	1,369	1·77	2·04	6·26	9·06	69	16·9	6·61	2,560
50	2,500	1·8	2·32	8·65	15·5	56	17·3	6·20	2,800
60	3,600	1·82	2·49	10·57	21·46	49	17·63	5·97	2,940

TABLE 6. Ordinary Iron (1 mm. thick).

f	f^2	n	$c \times 10^7$	$a \times 10^7$	$b \times 10^9$	$k = \frac{a}{b}$	$\frac{a}{f} \times 10^9$	$\frac{b}{f^2} \times 10^{12}$	kf
25	625	1·75	2·92	6·49	12·86	50	25·96	20·6	1,250
37	1,369	1·78	3·78	9·65	25·8	37	26·07	18·84	1,369
50	2,500	1·81	4·64	13·37	47·0	28	26·74	18·8	1,400
60	3,600	1·83	4·98	16·13	63·3	25	26·88	17·58	1,500

Table 7 shows the values of c_1 and n_1 for the three brands of iron, and Fig. 4 shows $\log n$ plotted against $\log f$. The values of n_1 and c_1 were obtained from the three lines shown in this figure.

When f and c were plotted the result was a straight line, which if produced would have cut the vertical axis above the origin, giving a positive intercept. Hence we may infer that, within the limits of frequency and flux density previously stated, c varies directly as the frequency. The lines obtained are shown in Fig. 5.

In determining the values of c and n for Lohys, it was found that the lower points had a tendency to lie on a slight curve concave upwards. This was due to the

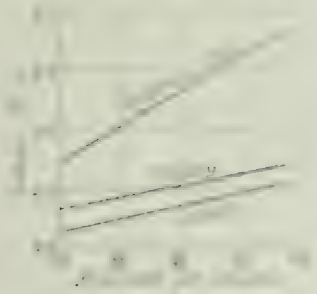
TABLE 7.

Brand of Iron	n_1	c_1
Stalloy ...	0·061	1·38
Lohys... ...	0·059	1·43
Ordinary ...	0·055	1·5

comparatively large hysteresis loss which is more prominent at low than at high flux densities.* The value of n in

* Although the variation of n is a small percentage, it makes a great difference in a calculation when used as an index, e.g. $10{,}000^{1·68} = 5·25 \times 10^6$, while $10{,}000^{1·77} = 12 \times 10^6$; so that an increase of about 5 per cent in the index has caused an increase of about 230 per cent in the absolute value. However, it must not be assumed that a small error in the determination of n will cause a large error in the value of W as calulated from the formula $W = c\,B^n$, because an error in n is practically compensated for in the corresponding value of c. Taking a case in point, suppose n in Equation (2) was 1·74, the corresponding value of c would be 2·92. Using these values, $W = 0·8$ when $B = 5{,}000$, and this differs from the curve by only 1·3 per cent. For larger values of B the error is much less, and is of the order of $\frac{1}{5}$ of 1 per cent in the neighbourhood of $B = 10{,}000$.

* The eddy-current loss at low flux densities was comparatively small owing to the plates being only 0·37 mm. thick.



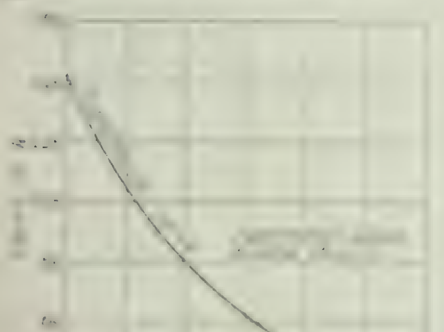


Fig. 6.

$$ \qquad (5) $$

Table

experimental values of a, b, and n, the corresponding values of the constant c can be calculated. Table 9 shows these values, the experimental results being given for comparison.

TABLE 9.

	Stalloy		Lohys		Ordinary Iron	
f	$c \times 10^7$		$c \times 10^7$		$c \times 10^7$	
	Experiment	Calculation	Experiment	Calculation	Experiment	Calculation
25	2·16	2·17	1·76	1·78	2·92	2·89
37	2·29	2·29	2·04	2·05	3·78	3·77
50	2·66	2·65	2·32	2·32	4·64	4·61
60	2·83	2·83	2·49	2·47	4·98	4·97

In calculating the values of n and c for Lohys the value of B used in Equation (6) was 20,000, which is considerably beyond the range; it will be advisable therefore to take these values with reserve. The large value of B can be accounted for by the fact that Equation (5) enables the minimum values of the expression $k\,B^{1 \cdot 6-n} + B^{2-n}$ to be found, and, as is mentioned in Appendix I, these values for Lohys lie outside the range.

Conclusions.

(1) That for flux densities between 4,000 and 10,000 lines per square centimetre, and frequencies between 25 and 60 periods per second, the combined hysteresis and eddy-current losses in Stalloy (0·5 mm. plates) or in ordinary iron (1 mm. plates) subjected to an alternating magnetization can be represented within 1·5 per cent by an expression of the form $W = c\,B^n$, n varying from 1·68 to 1·77 for Stalloy and 1·75 to 1·83 for ordinary iron.

(2) That for flux densities between 5,000 and 10,000, and frequencies between 25 and 60, the combined hysteresis and eddy-current losses in Lohys (0·37 mm. plates) subjected to an alternating magnetization can be represented within 2·5 per cent by an expression of the form $W = c\,B^n$, n varying from 1·73 to 1·82.

(3) That in the expression $W = c\,B^n$, c varies directly as the frequency, but the relation which exists between n and f is of the form $n = c f^{n_1}$.

The above work was carried out in the Applied Electricity Laboratories of Liverpool University.

APPENDIX I.

In view or the fact that, between the limits of $B = 4{,}000$ and $B = 10{,}000$, log W and log $B_{max.}$ invariably gave a good approximation to a straight line, the author was led to the following elementary mathematical analysis :—

$$y = a\,x^{1 \cdot 6} + b\,x^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$
$$= x^n\,(a\,x^{1 \cdot 6-n} + b\,x^{2-n}) \text{ where } n \text{ is} < 2 \text{ and} > 1 \cdot 6$$
$$y = c\,x^n \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

If (1) and (2) are approximately equal for the same values of x, then $c = a\,x^{1 \cdot 6-n} + b\,x^{2-n}$. Moreover, it is necessary to show that the expression $(a\,x^{1 \cdot 6-n} + b\,x^{2-n})$ remains practically constant for the values of a, b and n which obtain in practice, while x varies between 4,000 and 10,000.

Since a suitable series cannot be found for the above expression, its constancy is best demonstrated graphically.

$$a\,x^{1 \cdot 6-n} + b\,x^{2-n} = b\,(k\,x^{1 \cdot 6-n} + x^{2-n}), \quad \text{where } k = \frac{a}{b}.$$

As b is a constant multiplier for given conditions, the work can be simplified by plotting

$$y = k\,x^{1 \cdot 6-n} + x^{2-n}.$$

Taking the case of Stalloy when $f = 50$, we have $k = 60$ and $n = 1 \cdot 75$. Thus

$$y = y_1 + y_2 = \frac{60}{x^{0 \cdot 15}} + x^{0 \cdot 25}.$$

Fig. 7 shows y_1 and y_2 plotted separately and also combined, the combination giving rise to a curve which is only very slightly concave upwards and which has a practically constant ordinate; for as y_1 decreases, y_2 increases, and there is compensation. When $x = 7{,}776$, y has its minimum value, but the variation of y is so small that this value is imperceptible on the curve.

This is a particular case, but it is typical of what would be obtained by using other values of k and n which have been found experimentally. To verify this, the minimum values of $k\,x^{1 \cdot 6-n} + x^{2-n}$ were calculated for Stalloy and ordinary iron and were found to differ from the end values by less than 1 per cent.

In obtaining the values of c and n, if it is assumed that the mean line is drawn, this would correspond to the mean ordinate of $k\,x^{1 \cdot 6-n} + x^{2-n}$. Consequently the error of the results (on a theoretical basis) should not exceed about $\frac{1}{2}$ of 1 per cent.*

For Lohys the minimum values were outside the range, so that the end points only were considered. It was found that taking the end values, 4,000 and 10,000 gave just less than 5·5 per cent error as a maximum. Working on the mean ordinate basis, this would give an error of the order of 2·75 per cent. When the end values were 5,000 and 10,000 the maximum error was about 3·8 per cent, entailing on the mean ordinate basis an error of approximately 1·9 per cent.

Assuming that the expression $k\,x^{1 \cdot 6-n} + x^{2-n}$ is constant, it is possible to derive an approximate equation from which k can be calculated for different values of n, and vice versa.

The differential coefficient of a constant quantity is equal to zero, hence

$$\frac{d\,(k\,x^{1 \cdot 6-n} + x^{2-n})}{d\,x} = 0$$

$$\therefore\ (1 \cdot 6 - n)\,k\,x^{0 \cdot 6-n} + (2 - n)\,x^{1-n} = 0$$
$$\therefore\ (1 \cdot 6 - n)\,k + (2 - n)\,x^{0 \cdot 4} = 0,$$

since $x = 0$ is not a permissible solution,

$$k = \left(\frac{2 - n}{n - 1 \cdot 6}\right) x^{0 \cdot 4} \text{ approximately} \quad . \quad . \quad . \quad (3)$$

* Assuming that the mean ordinate between 4,000 and 10,000 is very nearly equal to the mean of the largest and smallest ordinates.

[illegible]

APPENDIX II.

[illegible]

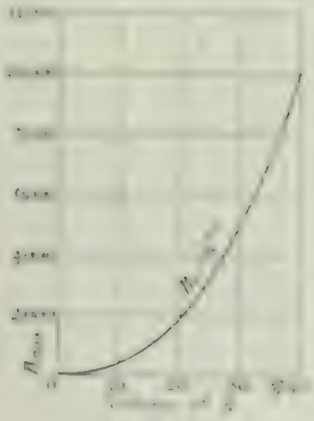


Fig. 8.

[illegible] Moreover for all values of k less than 40 the eddy-current loss is equal to and can exceed the hysteresis loss for flux densities less than [illegible]; for values of k greater than 40, the hysteresis loss exceeds [illegible]

[illegible]

APPENDIX III

[illegible] the flux density constant and varying the frequency, [illegible]

[illegible]

DISCUSSION ON

"CABLES." *

Newcastle Local Section, 14 December, 1914.

Mr. Vernier. Mr. C. Vernier (*partly communicated*): I should like to congratulate the author on the frankness that he has shown in discussing the design and behaviour of cables under various conditions. He has given to other manufacturers a lead which they might well follow with advantage both to themselves and their clients. On page 58 we observe one of the disadvantages of some forms of standardization; for the author points out what is familiar to some users, that there is less competition in the manufacture of standardized that in the case of unstandardized cable, and, further, that while "the opportunity for redesigning dielectric thicknesses was apparent years ago, . . . apparently nobody had the courage or opportunity to take the step of reversing the (existing) practice" which is so obviously contrary to good design. If such lack of progress results from standardization, one may perhaps express the opinion that the less standardization there is in such matters the better for the industry. In my opinion the thickness of insulation on cables is distinctly one of the things which we should not standardize. I need only recall the old-time Board of Trade regulation requiring that "the thickness of insulation on high-pressure cables in inches or fractions of an inch shall not be less than the number obtained by dividing the number expressing the volts by 20,000" (*i.e.* a 20,000-volt cable would have required not less than 1 in. thickness of insulation, as against 0·4 inch on the most recent similar cables), as probably the first step which led to the standardization of paper-insulated cables on the basis of thickness of insulation, but with what little scientific insight is in these days only too well known. With reference to Mr. Welbourn's remarks at Manchester† in connection with the possibility of raising the pressure on cables designed in accordance with the recommendations of the Engineering Standards Committee, it may be of interest to mention that this will shortly be tried under commercial conditions on several miles of 0·05 sq. in. 11,500-volt cables, which have worked for six years at this pressure and are now being changed over to the 20,000-volt network, the only alteration to the cables being the remaking of the joints in accordance with the latest practice for 20,000-volt working. One of these cables has already withstood a pressure of 20,000 volts continuously for over one month on a trial run. The author devotes the first part of the paper to considerations of design for very-high-voltage cables. Jona's method of grading cables based on the work of Messrs. Swinburne and O'Gorman is not, I fear, a very practical one. I share the opinion expressed by Mr. Sparks,‡ that engineers in this country do not wish to use cables constructed with more than one kind of insulating material. Jona's method almost certainly involves the use of rubber as a material with a higher specific inductive capacity than practically all others suitable for the purpose, but which is an extremely undesirable material to use on high-voltage cables if it can be avoided. The inter-sheath method offers perhaps greater practical possibilities, but there are some objections to the use of transformers,* while if condensers are used they would have to be of large size for any but the shortest lengths of cable, and would require to be insulated for the full working pressure of the cables to earth, resulting in a costly and cumbersome piece of apparatus. The need for 100,000-volt cable is not, in my opinion, likely to arise in this country for a considerable time, as I see very little prospect of long-distance transmission being required in such a densely populated country as ours. I think that high voltages will be used chiefly in order to reduce the number of cables required for extremely heavy loads. The use of single-core cables for 3-phase work, with the additional difficulties that they introduce, will, I feel sure, be avoided as much as possible as with 40,000-volt 3-core cables a practical possibility, and even the construction of 50,000-volt 3-core cables within measurable distance of accomplishment, these are likely to be the maximum voltages used in this country for many years to come. I do not think one need apprehend any serious difficulty in dealing with the large capacity currents. Such currents should to a certain extent be welcome in helping to raise the power factor of the system, and they have to be large before they effect any appreciable improvement in this direction. Should the need arise for single-core high-voltage cables to operate at over 50,000 volts for work abroad, which is perhaps a remote contingency, I have every confidence that very soon cable manufacture will have progressed sufficiently to enable such demands to be met in a simpler manner than either by grading or by the inter-sheath method described in the paper. In this connection it is well to observe that a 3-phase pressure of 100,000 volts with the neutral point earthed means less than 58,000 volts per cable; and if 40,000- or 50,000-volt 3-core cables are possible with the restrictions imposed upon the designer by small diameters and the shape of cable cores, the problem is much simplified when dealing with single-core cables and circular conductors, and with some latitude in proportionizing the core and insulation diameters. It may be of interest to call attention to an example of 30,000-volt single-core alternating-current cables operating in Germany, especially as full details of their design† have been published. The diameter over the lead is just under 2 inches, and the maximum stress 42,000 volts per centimetre against the author's 52,000 volts per centimetre (page 61). I am in agreement with the author when he states (page 61) that the original design of a cable has rather more direct reference to the test pressures than to the working pressures for which it is ultimately to be used. Test pressures of from three to five times the working pressure are purely arbitrary assumptions, and I am inclined to think that a method

* Paper by Mr. C. J. Beaver (see page 57).
† Page 64. ‡ Page 86.

* See page 83.
† High-tension cables on the railway between Dessau and Bitterfeld. *Electrician*, vol. 70, p. 1168, 1913.

[illegible]

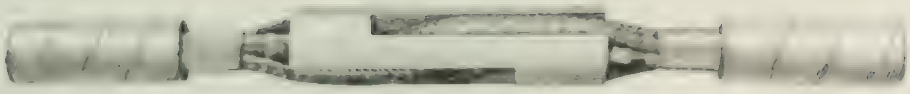


Fig. C.

Fig. D.

[illegible] 65 and 66 on expansion and contraction effects, it is well to note that these tests were carried out on a concentric cable of large size. One would, I think, naturally expect a very different behaviour with this type of cable from what would be obtained with a 3-core or a single-core cable, in fact it is well known that concentric cables are [illegible] I [illegible] however, agree with the author's final conclusion that [illegible]

[illegible] and leakage path between [illegible]

Mr. Vernier

this question of jointing very fully in 1911,* and from much the same point of view, viz. that of eliminating special skill in jointing. The type of joint which I then put forward with this object is that illustrated in Figs. 15 and 16 † of that paper, and is the one which in principle has been adopted on practically all the 20,000-volt cable-work carried out since that time in this country and abroad. The joint sleeves are now of somewhat different design and construction to allow for filling the joint under vacuum, but the internal insulation consists, as shown, of insulating tubes (now of paper instead of micanite, as described in the paper) kept apart by porcelain spreaders. These paper tubes are made of the same paper as the insulation of the cable, impregnated under vacuum at the cable works, and sent out in the sealed tins of compound used for filling the joint. If fibrous material is satisfactory for cable insulation, I do not quite follow what objection can be offered to adopting the same material over the bare cable joint, if as in this case it is treated at the works in precisely the same manner as the cable itself. In connection with this question of jointing, Fig. C herewith may be of interest. It shows the special form of joint * used for jointing each core of the oval concentric type of split-conductor cable used with the Merz-Hunter protective system. In order that the electrostatic capacity of each split conductor should be equal it is necessary to joint an inner split

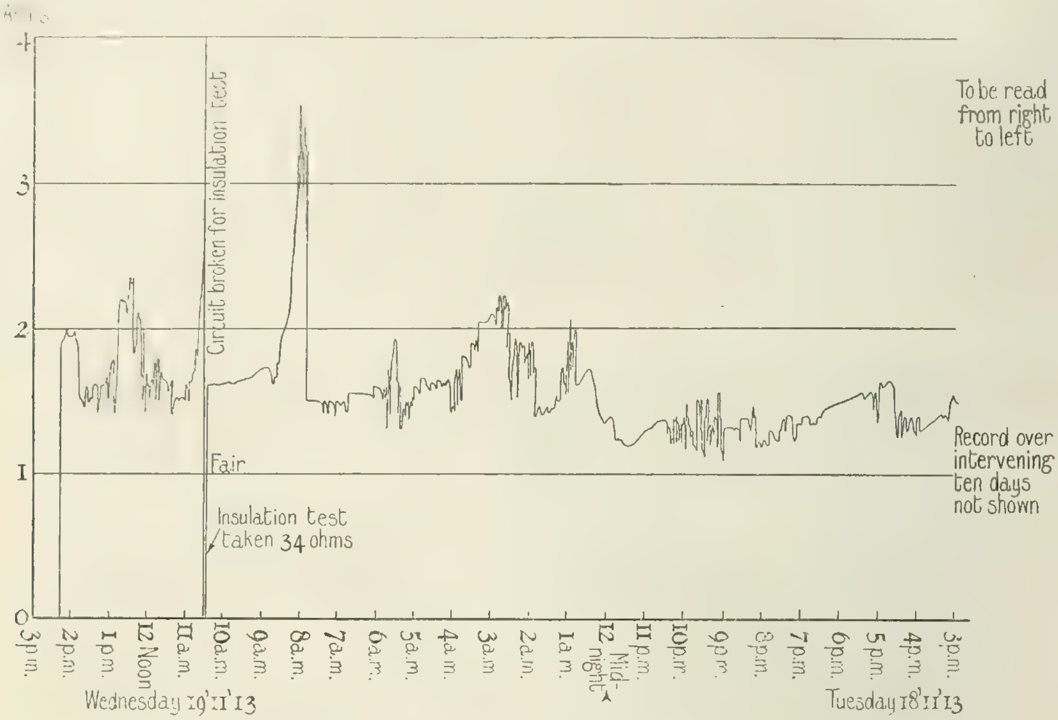


FIG. E.—Continuous-current Cable.

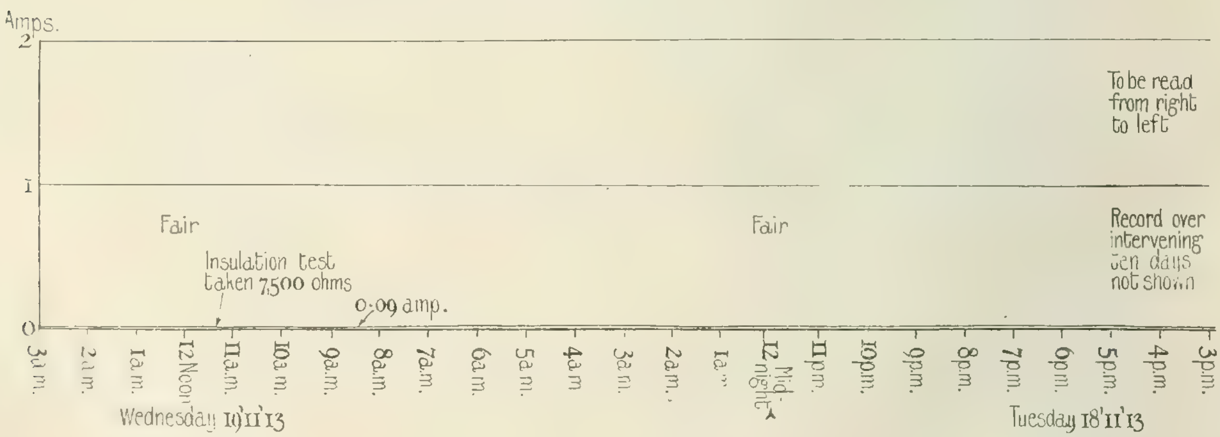


FIG. F.—Alternating-current Cable.

* C. VERNIER. The laying and maintenance of transmission cables. *Journal I.E.E.*, vol. 47, p. 322, 1911.
† *Ibid.*, vol. 47, p. 328, 1911.

* Patent 15413/09.

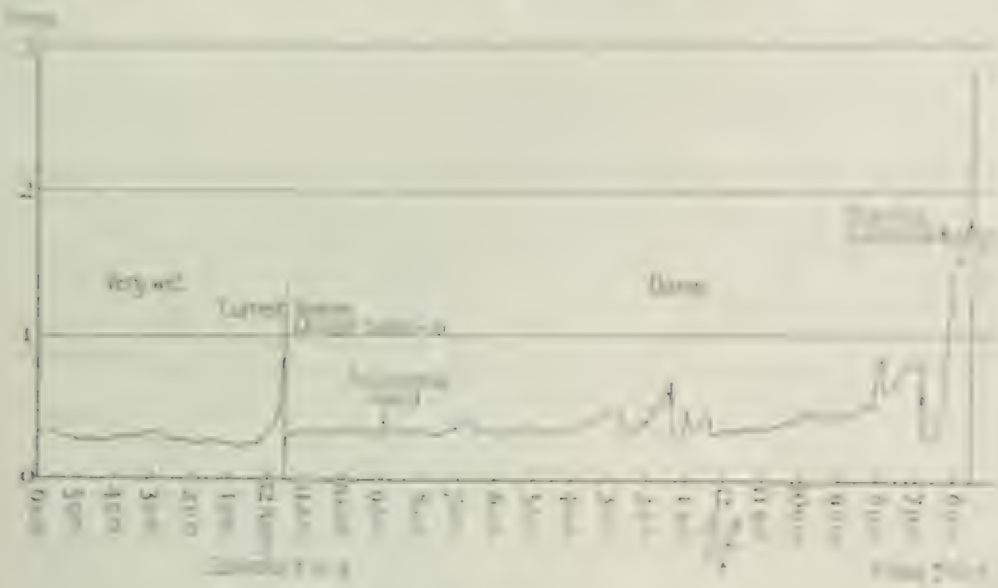


FIG. G.—Continuous-current Cable.

FIG. H.—Alternating-current Cable.

Mr. Vernier. the effect is one that can be repeated in a mild form in the laboratory on short pieces of cables; but the action is, however, somewhat slow and in the cases referred to it was quite four years after the cables were laid when the corrosion was first discovered. I am glad to say that the corrosion now appears to have ceased, probably owing to the exhaustion of the air, as no breakdowns have been experienced with the cables, although they have now been laid 10 years. There can be no excuse whatever for adopting wood for cable bridges or bushes of any kind in these days when so many excellent non-hygroscopic substitutes in porcelain, earthenware, asphalt, and other materials are supplied by manufacturers, and to do so only means incurring a risk out of all proportion to any saving obtained. The damage to cables laid solid from external vibration resulting in fracture of the lead sheath is not a new development.* The remedy on new work fortunately is simple, and consists in adopting armoured cables laid direct in the ground. I have yet to encounter the first case of damage from vibration with armoured cable laid direct in the ground, and I have used that type of cable almost exclusively during the past seven years.

The last part of the paper deals with vulcanized-bitumen cables, chiefly from the manufacturer's and chemist's point of view, and together with the author's previous contributions forms practically the only available literature on the subject. I can only deal with the question from the less-highly technical point of view of a user. I am sorry to say that vulcanized-bitumen cables have not fulfilled the high expectations credited to them at one time, and although for many years I favoured their use, I have gradually come to lose much of my faith in them. I should perhaps qualify this remark by saying I refer chiefly to vulcanized-bitumen single-core cables on continuous-current systems. Three-core cables, laid solid in bitumen, of which I have also had experience, have on the other hand given good results on continuous-current systems when well jointed. With single-core vulcanized-bitumen cables the chief trouble, as is well known, is due to electric endosmose on the negative cables. I here find myself unable to agree with Messrs. Dick and Fernie's argument quoted on page 74, and I personally support the theory of particles of moisture becoming forced through the insulation by electrostatic and capillary attraction as the initial cause of the leakage current. In support of this theory I would point out that the effect usually referred to as electric osmosis is, so far as my experience goes, quite unknown on vulcanized-bitumen cables of the 3-core type on 3-wire continuous-current systems, and if, as Messrs. Dick and Fernie state, the initial current is due to a fall of insulation resistance one would expect the same result with 3-core as with single-core cables on a 3-wire system. The electrostatic theory, however, agrees with the facts, and also explains the drying out of the positive cables, the accumulation of moisture on the negative cables, and the absence of osmosis troubles on lead-sheathed cables. Once a small initial current is established by the forcing of moisture through weak or thinned places in the insulation, usually caused by pressure upon it at some point, such as at a supporting bridge, or at an angle of the trough, etc., the action is cumulative and rapid. This leakage current produces a great deal of local heat and steam in passing through the surrounding soil, thus causing the insulation on the faulty negative cable, and frequently also on the adjacent sound positive and neutral cables to become destroyed, generally resulting in a short-circuit of all cables to earth. On the positive cables one experiences electrolysis caused perhaps by a minute crack, pinhole, or other defect, giving rise to a fault of high resistance and a leakage current which remains throughout of small value owing to the drying-out effect of the current, and is usually quite unobservable apart from the ordinary surface leakage on the network. In the course of time, generally a number of years, this small current destroys the copper conductor by electrolysis, until some day the circuit is broken and the supply, if fed only from one end, becomes interrupted. The ordinary fault-location tests are usually useless to find such faults, which can only be located by "tapping" the cable so as to find the point where the cable ceases to be "live." At one time vulcanized-bitumen cables were, I believe, largely adopted as the result of the electrolytic troubles experienced on lead-covered cables, but it would appear from this, and the effects summarized by the author on page 78, that such cables have developed some very distinct electrolytic troubles of their own. I have, however, never experienced the softening effects described at some length at the end of the paper, although I have seen specimens, brought from the tropics, of the cables referred to, which were quite unlike anything that I have yet come across in this country. In paragraph (*d*) on page 75 the author states that physically-similar effects are encountered on alternating-current cables, both 3-core and single, and also on positive and neutral cables. This is quite contrary to my experience, and I find that there is a very marked difference with vulcanized-bitumen cables in the effects encountered on positive cables and alternating-current cables as compared with negative and neutral cables, and especially with cables on alternating current as compared with continuous current. I recently carried out some experiments to demonstrate this, one of which is illustrated in Fig. D. Two cables, marked "A.C." and "B" in Fig. D, were taken, and a ring ½ in. long was cut out of the insulation in the manner shown in the specimen cable in Fig. D so as to expose the copper. Both cables were then buried in the ground without any protection, and at a sufficient distance from one another to prevent any interference. Cable "A.C." was made alive with alternating current from a separate machine through an alternating-current recording ammeter, and cable "B" similarly from the negative side of a separate continuous-current machine, both machines giving 240 volts, the other terminal of each machine being connected to earth. Records were taken of the leakage current, and the beginning and end of the records are shown in Figs. E, F, G, and H (to be read from right to left). It will be observed that although both cables started with approximately the same leakage current, and an initial kick, the leakage on the alternating-current cable dropped rapidly to just over 0·10 ampere, and continued with a steady, slightly diminishing value, ending up at 0·09 ampere, whilst the insulation resistance of the cable rose from zero to 7,500 ohms. The leakage on the continuous-current cable also quickly fell at first, but the variableness of the leakage current compared with the

* *Journal I.E.E.*, vol. 47, p. 333, 1911.

[illegible] give us some experimental or other proof that coal gas does [illegible] tively that I have met a genuine case of the vulcanized-bitumen cable itself being softened. I recently had an enquiry, however, on this question from an engineer, who claimed that a considerable length of his cable had been damaged by [illegible]

Professor W. M. THORNTON: There are one or two points which I should like to raise. Endosmose depends [illegible] ng electrical contact with opposite sides of [illegible] ere the water exudes. A few grains of carmine [illegible] le make the motion visible. At a frequency of 80 it is well marked, but at a frequency of several thousand it is not found. With regard to the penetration of membranes by current, I agree with Mr. Vernier that at first [illegible] transfer of water in the direction of the current, that is [illegible]

[illegible] and very sudden even in cl [illegible] thermal conductivity of the [illegible] enough [illegible] so that more current passes wi [illegible] on the elec [illegible]

Mr. [illegible] costs of the two cables shown in Fig. 3 and 4, viz. the [illegible] it seems to me that the split-conductor method would be [illegible] ductor rather than the lead tube. The most [illegible] while to use a slightly larger radius than this because the [illegible] sense [illegible] correct answer, but occa [illegible] equal to the ratio of the inter-sheath diameter to the [illegible]

[illegible]

Mr. Maccall. positions are wrong. The best place for the inter-sheath is between the two, but nearer the latter position. Reference to the curves in Fig. 5 gives a partial explanation of this result. Between the core and the inter-sheath the stress diminishes from 45 to about 15 kilovolts per centimetre. On the outward part it diminishes from the same value to about 28 kilovolts per centimetre. Thus some of the insulation inside the intersheath can be removed and used in a more efficient way between this and the outer lead cover. Again the author states that the limit of commercial usefulness of the inter-sheath cable is reached when the ratio of the inner radius of the lead cover to the radius of the core is five. It appears to me that the problem is rather that of designing a cable to stand a certain voltage, with insulating material which can stand a definite stress, so as to get the least overall diameter; consequently the correct way is to make the ratio of the radii of outer covering to core whatever value gives the best result. For a cable without inter-sheaths the best ratio is 2·72, as stated by the author. For a cable with one inter-sheath the ratio should be a little over five, so that the design given in the paper is not far from the best as far as overall diameter is concerned. I have not had an opportunity of referring to Dr. Russell's work, but it seems to me that for a cable with two inter-sheaths considerably better results could be obtained. Instead of making the ratio five, make it over eight and divide the insulation thickness into three unequal parts instead of three equal parts. By doing so a smaller cable can be used, and this method would also have the advantages of greatly reducing the cost of the inter-sheaths and also of reducing the capacity currents. In comparing cables in the latter respect a very convenient rule is that with cables designed for the same maximum stress the capacity current per mile is proportional to the radius (and is independent of the voltage). Thus by placing the single inter-sheath nearer the core than half-way, the capacity currents are reduced. I should like to know whether any attempt has been made to do something of that kind on 3-phase cables. Can an inter-sheath be usefully applied in a 3-core cable? With regard to the question of impregnating the paper before it is applied, in a previous discussion one speaker was under the impression that no cable-maker was prepared to do that. I know that Messrs. Glover & Co. did it 14 years ago. Perhaps the author will tell us for how much longer that has been his method. I have noticed in the electrical Press some correspondence in regard to the relative qualities of cables coloured red and black respectively. Some engineers say that black cable is much better than red. I should like to hear the author's opinion on that point. If the statement is correct, is there any chemical cause? Is it due to the difference in heat transference of the two colourings, or is it merely a coincidence? With regard to the testing of vulcanized bitumen referred to on page 73, would similar results be shown if the size were altered? Would two different qualities always give the same relative results, or does the size of the test piece fit some qualities of bitumen better than others? Even if it does, the value of the tests is not destroyed. It is possible that these tests will enable us to ascertain which kind of bitumen is the best for insulating cables for ordinary voltages. Suppose, however, the insulation thickness is different, is the same quality still the best, and would the bitumen which appears to be the best with one size of test specimen still show the best results if another size were used?

Mr. H. Bridges: On page 58 the author states that the conductors for high-voltage cables would invariably be made in hollow form. The manner in which he prefers to form the hollow core, viz. to use a substantial lead tube, may be all right from the manufacturer's point of view, but from that of the user it does not appeal to me on account of the increased weight of such a cable owing to the addition of the lead tube, which increases the diameter of the cable and therefore the weight of the outer lead covering. It would be very interesting to know how the increased efficiency, due to the use of the hollow core, compares with the increased cost of manufacture and laying. I should like to know whether it is necessary for the core to be hollow, and whether the same results could not be obtained by the use of a solid paper inner-core instead of lead. The hollow core appears to be an objection from the point of view of jointing; there are quite enough complications now in the jointing of high-voltage cables without adding to their number. The compound used for filling joints would run down the hollow cores, unless it is proposed to seal them up: or is it intended to make the lead tube continuous through the joint? The comparison at the top of page 59 between the overall diameters of the cables shown in Figs. 3 and 4 does not seem fair, as the cable shown in Fig. 4 has twice the carrying capacity of that in Fig. 3. Whatever can be done to reduce the thickness of the dielectric to a minimum should be done. The manufacture of high-voltage cables necessitates increased thickness of the dielectric, and in consequence of this the location of faults on such cables is becoming very difficult. A cable may break down, but the insulation resistance when measured gives a value of several megohms, and it takes some considerable time before the conditions are such that a localization test can be made. In one instance of the breakdown of a 3-core 20,000-volt cable, when a test was made it was found that the insulation resistance between two cores and between these cores and earth was 40 megohms, whilst the third core gave 3 megohms with all cores continuous. This necessitated sending for a heavy pressure testing transformer in order to break down the insulation of the third core. After the breakdown pressure had been applied to the third core, instead of the insulation resistance of that core being lower, it had increased to 10 megohms. This is typical of what occurs, necessitating continual pressure testing until finally conditions are secured for a localization test. The difficulty of obtaining satisfactory conditions for such a test is due to the large thickness of insulation. With the use of the split-conductor concentric type of cable (Fig. 4), the difficulty of locating faults will, I believe, be considerably diminished, as suitable conditions will almost surely be obtained between the splits. In the grading of dielectrics, the insertion of the inter-sheath (which the author prefers should be of lead, Fig. 6) would serve a useful purpose in the location of faults, as the breakdown current would have to pass through the inter-sheath to the outer lead covering, and a short-circuit would more easily be obtained between the core and inter-sheath or between the inter-sheath and outer covering, which would give good conditions for a localization test. On the other hand there

[illegible]
district we have had a good deal of trouble due to vibra-
[illegible]
several 3-wire single-core cable networks in this district
[illegible]
required about [illegible]

[illegible]
conductors by the author. For [illegible]
[illegible]

some 14 per cent higher than this. This cable has now been in operation under full working pressure for several years. Taking next the typical conductor worked out by the author for a 50,000-volt cable, in which he finds the most economical diameter over the conductor to be 0·8 in., he endeavours to obtain this in copper by stranding the wires over an inner lead tube, afterwards covering the whole conductor with a thin lead sleeve so as to present a smooth surface to the dielectric. Assuming average prices of £60 and £20 per ton for copper and lead ingot respectively, the cost of the metal in this case (exclusive of working up) is about £148 per mile. If aluminium wires of equal resistance be substituted for the copper wires, then not only will the cost of such wires be considerably lower than the equivalent copper wires, but owing to their larger area the size of the inner lead tube will be reduced accordingly with a corresponding diminution in cost. As a matter of fact it would cost very little more to fill completely the whole space with aluminium wires, doing away with the lead tube entirely, as bulk for bulk aluminium is as cheap as lead, the only saving in favour of lead being due to the hollow centre, which for most cases would be negligible where aluminium wires are employed. Assuming, however, that a lead tube be employed as for copper, and of equivalent thickness in proportion to its diameter, and taking average prices of £80 and £20 per ton for aluminium and lead ingot respectively, the cost of metal (again exclusive of working up) is only £95 per mile. The drawing and working up of the conductor and lead would be about the same in each case, as the larger section in aluminium is offset by the smaller number of wires and the lower weight of lead to be handled, so that we can safely say that as far as the conductors are concerned, there would be a clear saving of £53 per mile in favour of aluminium under these conditions, or more than one-third the cost of a copper conductor. Turning next to rubber-insulated cables, the author devotes considerable space to discussing ways and means of preventing the deterioration due to the action of the sulphur in vulcanized rubber on copper, even when the latter is protected by a layer of more or less pure tin. It is of course well known in the rubber industry that aluminium is absolutely unaffected by the sulphur in vulcanized rubber, and good use has been made of this knowledge in recent years in the designs of mandrils and similar apparatus required in the rubber industry, aluminium being almost exclusively used for these purposes. This fact has also led to the employment of aluminium rubber-insulated cables in many difficult situations, where corrosion of the copper wires was to be feared, as for instance in sewage work; it is therefore rather surprising to find the author making no reference to the matter in his paper. The same remarks apply to bitumen cables, more especially when strengthened by the addition of rubber compounds, and for this class of low-tension cable the economy in favour of aluminium is usually very marked. Another point that has often been overlooked is that aluminium, being bulk for bulk one-third the weight of copper, the tendency to decentralize at high temperatures is divided by three, as the pressure per unit area is only one-third.

Mr. Beaver. Mr. C. J. BEAVER (*in reply*): I think Mr. Vernier has rather misinterpreted my remarks regarding the standardization of dielectric thicknesses. In the early days of e.h.t. work, the standards of manufacture and scientific knowledge of the numerous considerations involved in the production of e.h.t. cables were not greatly out of proportion to the somewhat empirical lay-out of the standards adopted. In fact the criticism which might have been expected on this point would perhaps have related to the ease of being wise after the event. The reference to the old Board of Trade regulation in this connection is not quite fair, because at the time it was made no higher pressure than 2,000 volts was in general use. It will be interesting to know the result of the changing-over from 11,500 to 20,000 volts of the cables mentioned by Mr. Vernier, and I would specially emphasize the importance of taking into account the previous history of these cables when judging the results. I refer to such points as the maximum and average current densities at which they have been worked, troubles which had previously occurred on them due to working conditions, differences in voltage waveforms at the two pressures, and so on. Mr. Vernier's views as to the disadvantage of capacity grading by varying the composition of the dielectric material, as compared with inter-sheath grading coincide with those expressed in the paper, but his objections to the latter method on account of modifications to or additions of external apparatus in connection therewith are not by any means insuperable. In fact for the case in which the probability of the use of a working pressure of 100 kilovolts is admitted, *i.e.* connecting cables for extremely heavy loads, these grounds of objection will be reduced to a minimum because the length of such cables will not be so great as to necessitate the insertion of condensers or compensators, etc., at intervals.

Mr. Vernier's view, that the large capacity currents which of necessity accompany the use of high-voltage insulated cables will be to an extent beneficial in raising the power factor of a system, is interesting in view of the dread of capacity currents which has been expressed by other speakers elsewhere in the discussion. It is of course a matter of degree, depending in a general way on the load factor of the system. Under heavy load conditions the proportion of plant occupied in dealing with the capacity currents in a given case would be small, and at the same time the beneficial effect on the power factor of the system would be at a maximum. At light loads the reverse would be the case, with the additional possibility referred to by Mr. Hunter of encountering the Ferranti effect due to preponderance of leading current.

I am glad to have Mr. Vernier's agreement as to the desirability of using some such method as Mr. Addenbrooke's of observing the relation between power factor and test pressure, in place of the comparatively crude method of simply stressing the dielectric by the application of a test pressure having some more or less arbitrary relation to the working pressure. Especially is this desirable in the case of heavily insulated cables, on account of the effects referred to in the paper under the heading of "Time element in pressure tests."

In reply to Mr. Vernier's questions on the method of impregnating paper, the process referred to in the paper as preferable [Paper Insulated Cable. Section 1, subsection (*b*)] was used for the 100 kv. cable, and has been used commercially for the past 17 years in cables for all voltages, with satisfactory results.

With regard to expansion and contraction [illegible] cables, I quite agree with Mr. Vernier that [illegible] Mr. Vernier's [illegible] With regard to filling [illegible] [illegible] volts I have [illegible] skilled, beyond spacing, enclosing, and filling. The form of split-conductor joint shown by Mr. Vernier is very neat and compact and should be of great service for the [illegible].

With reference to the corrosion of lead sheaths in contact with wooden bridges, the case instanced by Mr. Vernier does not appear to me to be strong enough to refute my statement that serious cases of corrosion at wooden bridges are invariably due to electrolysis and not to simple chemical corrosion. The conditions described [illegible] A [illegible] out current, particularly in the case of oak, but a sufficient amount of vegetable acid would not be available for anything more. My statement in the paper was based on such a large number of instances and on such a mass of evidence that I am afraid Mr. Vernier's case does not shake [illegible].

The type of mechanical damage to lead-covered cable [illegible] should not be confused with [illegible] as Mr. Vernier says, are not new. The description in the paper, *i.e.* "pounding," is more [illegible] and troughing, the effect of which is localized at the [illegible] which prevents this localization will be a palliative, and [illegible] trouble is not en-[illegible]

Mr. Vernier's statement [illegible] with single-core vulcanized-bitumen cables on continuous-[illegible] [illegible] and incidentally supports the results of the [illegible] trolytic troubles on lead-covered cable [illegible] vulcanized-bitumen [illegible] sheathing material.

Referring to Mr. Vernier's experiments w[illegible] in vulcanized-bitumen single-core cables, he appears to [illegible] I referred to the second type of [illegible] connection with the conditions of Mr. Vernier's [illegible] ments, and which he states he has never [illegible]. So far from his results differing from my experience, they [illegible] vicinity of the alternating [illegible]

[illegible] bitumen, I may [illegible] the past few yea[illegible] materials, [illegible]

general character of the action may be briefly stated as follows :—

The effect of coal gas on many of the compounds is similar to that of a solvent, producing (more or less superficially) a very viscid solution which will tend to flow, exposing a less saturated surface which in turn absorbs more gas. In general, as might be expected, the heavier constituents of the gas are absorbed, but in some materials there would appear to be a selective absorption of both light and heavy constituents, as shown by gradually raising the temperature of exposed specimens in a flash-point test apparatus, when flashing may be observed over either a long or short range of temperature, or may occur over a low temperature range, followed by a range over which no flashing takes place, and in turn succeeded by another range giving continuous flashing corresponding to heavy constituents absorbed.

The effect on rubber is well known (laboratory gas-tubing affording an instance showing absorption without softening), and vulcanized bitumen may be broadly considered similar. In cables, however, there is practically always in contact with the vulcanized bitumen some material (such as tape serving compound) which tends to become liquefied by the absorption of gas, and this tends to soak into the vulcanized bitumen. This might give the casual observer (by comparison with a part which has not been exposed to the gas) the impression that the vulcanized bitumen had been slightly dissolved, but exposure of the vulcanized bitumen itself shows no softening in the sense of solution or liquefaction, which would tend to allow it to lose its shape or resilience.

Professor Thornton's remarks on endosmose are interesting, particularly as regards their bearing on the results of Mr. Vernier's comparison of alternating and continuous currents. I would point out, however, that it is not correct to regard a wall of vulcanized bitumen as a "membrane," as the word implies a chemical composition and physical structure which is very different. It is possible that a large part of the misconception which exists in connection with the electric endosmose effect as a factor in the development of cable faults is due to lack of distinction between what happens with a membrane through which diffusion may occur, or a porous diaphragm, and a dielectric material which, if sound and homogeneous, has the properties of neither. It is explained in the paper, and I think proved, that it is necessary to have a fault at least in an incipient state before appreciable electric endosmose can occur. It may be argued that the matter is one of degree, but it seems certain that the degree is outside the range of practical conditions.

With regard to the action of coal gas on bituminous substances, Professor Thornton's remarks are perhaps sufficiently dealt with in my reply to Mr. Vernier.

The development of Professor Thornton's work on the relation between thickness and breakdown voltage in dielectrics will be eagerly looked forward to by those interested in the subject. The glimpse that he has given us of his conceptions of the mechanism of the breakdown process is extremely interesting, and although difficult to demonstrate electrically in the absence of an ideal dielectric, the molecular collapse or subversion which, in effect, he pictures, has its parallel in certain chemical actions.

He rightly lays stress on the importance of heat conductivity in dielectrics, and I would point out that the Mr. Beaver
method of grading by varying the capacity and therefore the composition of layers of dielectric material tends to disregard this.

I think Mr. Maccall's question as to the relative costs of the two conductors shown in Figs. 3 and 4 arises from a misapprehension. The facts of the matter are, that for given conditions of working pressure and maximum stress in the dielectric there is a certain radius of conductor which gives the most economical cable. The required conductor area depends, of course, on the horse-power to be transmitted, and at very high pressures the area corresponding to the most economical radius will usually exceed the area required for conducting purposes. It is therefore economical to construct the conductor in hollow form, and for reasons connected with the maintenance of the cylindrical shape of the stranded conductor, the construction shown in Fig. 3 is found to be preferable. Given these conditions, Fig. 4 simply illustrates that for the same conditions of working pressure and dielectric stress split conductors with the requisite amount of insulation between them may be embodied without interfering with the conductor-radius conditions. Relative costs are not necessarily therefore of any interest unless one is comparing two propositions.

Mr. Maccall's criticism with reference to the half-way position of the inter-sheath in the dielectric of the single-core inter-sheath cable is quite sound from the theoretical point of view. The explanation of the slight departure from the theoretically best position is that it is preferable from the cable manufacturer's point of view to deal with two equal thicknesses of dielectric rather than thicknesses which differ by 60–70 per cent, which would be the case if the inter-sheath were accurately placed in the best position from the stress point of view in the cable in Fig. 5 referred to by Mr. Maccall. The following theoretical figures, in

Case	Position of Inter-sheath in Dielectric	Potential Differences in Kilovolts between		Values in mm.	
		Conductor and Inter-sheath	Inter-sheath and Lead Covering	r	R
1	1/4	20·5	54·5	6·57	32·9
2	1·5/4	25·9	49·1	6·28	31·4
3	2/4	31·35	43·65	6·33	31·7
4	2·5/4	37·5	37·5	6·65	33·3

which the thickness of inter-sheath has—for the sake of simplicity—been ignored, show, however, that, keeping to the R/r ratio of 5, the value of r is little affected by moving the position of the inter-sheath within fairly wide limits. The value of R is therefore only slightly varied, and the degree to which the overall diameter and consequently the cost of the cable is affected by this concession to manufacturing considerations is almost inappreciable. They also show the effect on the voltages between the conductor and inter-sheath, and between the inter-sheath and the overall lead sheath of the cable.

[illegible] relative durability forecasted by watching the changes in [illegible] temperature conditions. The avidity with [illegible] occur more often on red than on black-finished cables is that the red compound more frequently contains resinous matter. The attainment of the colour by dyeing the wax (as distinct from colouring by pigments) is facilitated by [illegible] entered on here, but it should be borne in mind that the presence of resin is not essential although its exclusion entails extra cost. It is only fair to add that in the great majority of cases, so far as British manufacture is con[illegible]

[illegible] inclined to think that Mr. Maccall's question as to [illegible] of the size of test piece in the physical tests [illegible] bitumen described in the paper arises from [illegible] contributed. I would point out that different qualities are not used for different sizes of cable, and that the object of the physical tests is to control the physical [illegible]

[illegible] there is already a tendency in some quarters to regard the [illegible] necessary feature of the construction of such cab[illegible] simply because of its constant availab[illegible] ductor, but because of its favoura[illegible] also readily be utilized in conjunction [illegible] localization. Mr. B[illegible] in the event of a s[illegible] between the inter-[illegible]

[illegible] exactly with the insta[illegible] the pounding effect of he[illegible] I am glad to note that he clearly di[illegible]

take up a position in electrical work which will be approximately determined by the balance of its advantages and disadvantages.

With regard to Mr. Piercy's reference to aluminium being unaffected by the sulphur in vulcanized rubber, he would appear to have missed the chief significance of the reference in the paper to rubber in contact with aluminium. The action of sulphur on a rubber-insulated conductor is a comparatively insignificant matter, the chief virtue of aluminium being that it does not act catalytically as an oxygen carrier to the rubber as copper does.

Mr. Piercy's further remarks on rubber-insulated aluminium cables appear to be made with the object of finding ground for the surprise he expresses that no reference to such cables is made in the paper. It is surely straining the point to say that aluminium has been used as a conductor for rubber-insulated cables where corrosion of the conductor metal has been feared. Sewage and the like should not reach the conductor if it is really well insulated. Mr. Beaver.

The bulk-for-bulk comparison of aluminium with copper mentioned by Mr. Piercy in his reference to bitumen cable seems to lack point, as the basis of comparison should be conductivity for conductivity, and even then the comparison as regards mechanical pressure on the dielectric due to weight is not accurate.

SCOTTISH LOCAL SECTION, 12 JANUARY, 1915.

Mr. D. A. STARR: The subject dealt with is one of great importance, and this paper appeals especially to those who are engaged in the generation and transmission of electric power for industrial purposes over an extended area. It is unfortunate that the author has confined his remarks so largely to paper-insulated cables intended for transmitting energy at pressures far beyond the range of present-day practice in this country. It is a very doubtful point as to whether in Britain a 50 or 100 kw. transmission scheme could be justified. The plant capacity required for charging the cables alone would present difficulties which considerations of sound finance could scarcely surmount. Having regard to our extensive coalfields and our readily accessible seaboard it would seem to be a sounder proposition to select a power-station site with abundant condensing water and the use of sea-borne coal with its low freight charges, and to generate at a pressure not exceeding 20,000 volts, rather than to select a site at a remote coal-field and transmit at 50,000 or 100,000 volts. Had we a Niagara or Victoria Falls within the United Kingdom the case of course would be different and the author's visions might more readily have materialized. The Thury constant-current system as applied to the Metropolitan Electric Supply Company's area for variable pressure up to 100,000 volts is of course an exceptional case. One cannot but feel that this system has a very limited field of application on account of the difficulty of applying to it any of the modern systems of protective devices which alone can ensure reasonable continuity of supply. The design for a single-core conductor shown in Fig. 3 may be satisfactory from the standpoint of the designer and even from the standpoint of the manufacturer, but any engineer who adopted it for his transmission cables would, I am afraid, have very solid reasons for regretting his choice. Let us consider this design for a moment and see what we have got. First of all we have two elements, copper and lead, each with a different coefficient of expansion. It seems more than likely that with a high current-density the heating of the conductor would lead to the permanent deformation of the lead lining and sleeve, more especially when it is borne in mind that lead has little or no resiliency. A second and fatal objection is the air space in the centre of the conductor. In the descriptive matter relating to the vitrified porcelain spreaders shown in Fig. 16 a special point is made of the fact that these spreaders are shaped to resist any tendency to trap air or gases, and yet in Fig. 3 we find a formation of conductor which actually embraces an air cavity as an essential feature of the design. It is a common experience with 3-core paper-insulated cables which have been so built as not to exclude all interstices in which air may find a lodgment, that serious troubles arise at the end boxes due to the imprisoned air expanding under rising temperature. This air finds its easiest escape through the compound in the end boxes, leaving a pinhole in its path through which damp air may be drawn when the temperature of the cable returns to normal. Very often the end-box design is blamed for what is really an inherent defect in the cable design or manufacture. Perhaps the author would give some further particulars as to what constitutes a good paper for use as a dielectric. I know the general impression amongst engineers in this country is that pure Manilla paper only should be used. When I was at his works in Switzerland a year or two ago, Dr. Borel stated that he considered a pure Manilla paper to be much inferior to Manilla with a small proportion of wood pulp. He at the same time expressed the opinion that pure Manilla paper was not sufficiently porous to absorb the necessary quantity of the insulating oil or compound, and that from his experience, extending over many years, he did not approve of pure Manilla paper. Regarding the case of alleged mechanical damage at Manchester, it would appear that the trouble experienced is more likely to be caused by the accession of moisture through the joints in the troughing, assisted probably by the presence of cable supports. It seems highly improbable that the cable and troughing would be displaced, as obviously the ground under the troughing must have yielded by a corresponding amount. The corrosion of lead sheathing at troughing joints is no new phenomenon, and can easily be got over by a modification of the design of support used for keeping the cable central with the troughing. The author refers in this connection to the wooden bridge-pieces serving as a conductor. This in itself is no disadvantage. The real danger in wooden bridge-pieces lies in the fact that it is almost impossible to eliminate the free acids in the wood. Steel is used in the Ruthven Murray bridge-piece, and the support is so shaped as to sling the cable from the sides of the trough. Regarding bitumen cables there is one point which is sometimes overlooked, namely, that owing to the temporary failure of an important feeder the remaining feeders may be required to transmit considerably more than their normal current for several hours. Whilst paper- Mr. Starr.

[illegible]

Mr. [illegible] [illegible] 66), but perhaps the author will explain their seemingly [illegible] returning to its own again now that safeguards are provided against leakage of current to and from the sheath ; but the [illegible] [illegible] variation, or rough handling, some- [illegible] (referred to on page 69) alter not only with the growth of a network but hourly with the diversity of the load. It is [illegible] bitumen, but I still imagine that moisture, even if slightly alkaline but without current leakage, will not deeply injure vulcanized bitumen within any period of time likely to [illegible] by capillary attraction is apt to be driven by electric exosmotic action radially outwards against and perhaps into the dielectric. There is need also for non-hygroscopic [illegible]

[illegible]

Mr. [illegible] [illegible] use, this will have the effect of still further increasing the [illegible] that opinion is correct. On page 68 the author states that there is a much better chance of making a lead-sleeve joint [illegible] the difficulty in sealing the box at the ends ; but then the [illegible] often are such that a wiped joint proves defective. In [illegible] sleeve is used, the ends being joined solid on to the lead [illegible] and sleeve. An absolutely watertight joint is obtained, [illegible] special labour is required and there is no uncertainty as to [illegible] The separator which is used in Glasgow is on the same [illegible]

Mr. Mitchell. of locking the outer part of the spacer to the inner. I think that with the separator in one piece, which is slipped over the cores before the ends are sweated, the paper is not strained nor are the cores displaced to the same extent. The author's theory that the corrosion of lead coverings, notably in contact with wood saddles, is due entirely to electrolysis may be the correct one. I formed the impression at one time from my own experience that the sap in the wood accounted for the corrosion and that the action was chemical. It was found that when oak was used for this purpose the corrosion was rapid. When the oak was changed to ordinary white wood the action still went on but very slowly. Admitting that the lead covering of the cable would from time to time become alive, and that the cast-iron troughing in use made a good earth, the author's theory is, I think, borne out. With reference to rubber cables, I regret to learn that their maximum strength and elasticity are not compatible with maximum insulation resistance, and that unscrupulous manufacturers can so fake rubber that while improving its mechanical properties the insulation resistance will not only be reduced but the rubber become an absorbent of moisture. A supply authority in testing samples of cables submitted must rely for the most part on mechanical tests. These tests need not be severe. For instance, it is known that the rubber on a cable carried round a sharp bend is stretched to twice its original length at the outer part of the bend. Surely, then, it may be stipulated that a sample of rubber under test must stretch to twice its length without breaking. It is only by tests of this description that inferior grades of cable can be kept out. Referring to the tinning of copper wires, I am not quite clear as to the author's meaning when he speaks of the appearance of the tinning after the cables have been removed from the vulcanizing chamber. Is it the tinning only which is under suspicion when it has a silvery bright appearance, or must we also suspect the quality of the rubber? In a paper read some years ago by the author on rubber cables for interior wiring, he made the same statement, viz. that perfectly white tinning should be regarded with suspicion. If the tinning only is at fault when bright, does this point to an undue proportion of lead in the tin? With regard to bitumen cables, the results obtained in Glasgow with cables of this description have been excellent in cases where the solid system has been used, but when drawn into ducts the results have been unsatisfactory, more particularly with small cables. The arc-lamp circuits over the whole city were composed of bitumen cables drawn into iron pipes. The bitumen was found to crack in some cases and to soften in others. Breakdowns have been frequent, and a considerable quantity of the original cable has had to be taken out. The author's statement that vulcanized bitumen is not affected by coal gas is interesting. I think the worst failure of bitumen cable experienced by us was in the case of one of the arc-lighting cables already referred to, which was in a pipe kept continuously full of gas for some considerable time from a leaky gas main in the vicinity. This piece of cable was drawn out with the bitumen in a jellied condition, this condition being attributed to the presence of coal gas. This is only one of several instances which have been brought to my notice of the apparent softening of bitumen cables from the action of coal gas.

Mr. A. F. Stevenson: In the discussion on Dr. Russell's paper* Mr. G. H. Nisbett, who has had considerable experience with extra-high-tension cables, was of the opinion that there was no evidence that small-conductor e.h.t. cables broke down more readily than others in spite of their high surface curvature and usually thinner dielectrics. How can the inner layers of insulation be broken down if the outer part is intact? Where does the current which has penetrated the inner layers go to? Paper is not a gas; there is no brush discharge or similar effect which would be necessary if there were any need for enlarged conductors. To use the old hydraulic analogy: consider a cast-iron pipe of 1/10 in. bore and 5 in. walls carrying water at 100 tons per square inch. According to Dr. Russell's reasoning the metal near the bore ought to be crushed to powder, but we know that that would not happen on account of the backing of materials which is not stressed beyond the breaking point. In the same way with a cable, as long as the stress in the outer layers is not greater than the dielectric strength of that material no breakdown will occur, no matter how the inner layers are stressed. In practice the outer 100 mils could be worked at 50 kilowatts per centimetre. The stress on the inner layers may be limited by hysteresis heating only. Throughout the remainder of the paper the author is on solid ground. The only cases of non-electrolytic corrosion of bitumen that I have encountered occurred near alkali waste-heaps, urinals, and mews; free alkali in every case. The non-soapy softening effect is very interesting to me, as I experienced one case and was completely baffled by it. It occurred in a colliery shaft after many years in a steamy atmosphere. I prefer a slow extension test at 22° F. for bitumen, as bending in laying causes a slow extension. Any engineer who allows it to receive blows or shocks deserves faults. The penetration test is a very sound idea. Mr. Stevenson.

Mr. E. V. Pannell (*communicated*): Although the use of 75-kilovolt underground cables would not appear to be a matter of the immediate future, the study of the construction of conductors for these high pressures, as described by the author on pages 58 and 59, is of considerable interest. I believe that with the development of overhead-line engineering in Canada the field for underground cables at exceedingly high pressures will be very limited and confined to pressures ranging from 10 to 33 kilovolts. For these voltages, however, the radius of the core must be increased beyond that necessitated by considerations of conductance, as explained by the author, and in this field the use of an aluminium core instead of a copper core has already received consideration. For the same conductance an aluminium cable will have a radius just 30 per cent greater than the equivalent copper cable. Considering a given size, say a 0·093 sq. in. cable for a pressure of 30,000 volts (R.M.S.), the voltage gradient in the dielectric is given by $\frac{E}{r \log (r+d)/r}$, where r = radius of the core and d = thickness of the dielectric. In an actual instance in which an aluminium cable was used, the equivalent cross-section of the cable was, as above, 0·093 sq. in. The actual cross-section in 60 per cent aluminium was 0·155 sq. in.; therefore $r = 0{\cdot}256$ in. and $d = 0{\cdot}512$ in. Hence the Mr. Pannell.

* A. Russell. The dielectric strength of insulating materials. *Journal I.E.E.*, vol. 40, p. 6, 1908.

[illegible]

Mr. C. J. [illegible] [illegible]

[illegible] plant required for charging current alone would be a commercial bar to the use of [illegible] but in any case it is a matter which will constitute a powerful factor in determining the extent to which [illegible] cable will be used, either for feeding overhead lines or connecting large sources of power, and will settle itself on an economic basis.

In reply to Mr. Starr's [illegible] of the hollow type of conductor from the user's point of view, I [illegible] to avoid perceptible I^2R heating. Heating due to dielectric hysteresis will also be kept low. The total heating will therefore not vary much with variations in load. The trouble anticipated by Mr. Starr due to the difference [illegible] With regard to [illegible] by air being driven out of the lead tubes, the joints in these [illegible] so made that the tubes will be continuous throughout the cable and its joints. At end boxes the lead tubes will be [illegible]

[illegible] The [illegible]

In reply to Mr. Starr's [illegible] since learned that the same effects have been observed [illegible]

With regard to the [illegible] having special [illegible] cables [illegible] modern [illegible] and have [illegible]

Mr. Munro's suggestion that the test sheath should be [illegible] due to it, the cost of such [illegible] cables it is [illegible] affording maintenance test facilities, but [illegible] protective gear in conjunction with it.

In reply to Mr. Munro's [illegible]

Mr. Beaver. Unfortunately, space did not permit of details of this arrangement being shown in the paper, but they were sufficiently taken care of in the actual experiments. Mr. Munro's remarks with regard to the value of lead sheathing when safeguarded against the causes of its early troubles are very true, and they will be found to apply to other materials in exactly the same way now that the nature of the effects of various deteriorating agencies are understood. The whole field of deteriorating effects and their remedies may be divided under three headings: (*a*) The detection of the effects; (*b*) the determination of their character and origin; (*c*) the application of preventive measures based on (*a*) and (*b*). The safeguarding of lead coverings has been dealt with more easily because (*a*) and (*b*) were more simple than in the case of vulcanized bitumen.

Mr. Munro rightly attaches value to solid strand filling and non-hygroscopic coverings, though in most cases where the function of outer coverings is simply mechanical there is no reason why they should not be in the cheap form of more or less hygroscopic substances served with preservative compounds. The exosmotic action referred to by Mr. Munro is not so well appreciated as it should be. In the first place, the atmospheric conditions which can produce condensation of moisture at exposed ends occur much more frequently than would be supposed, and it frequently happens that moisture is accumulated in strands of rubber cables near unsealed ends in this way. In the presence of the free sulphur in the rubber, acid products may be formed which attack conductors, forming substances which crystallize out and force their way into the rubber. Incipient faults thus formed are subject, on positive cables, to exosmotic action, which slowly develops them.

In further reply to Mr. Munro, bitumen in admixture with rubber gives no appreciable advantage from the physical or electrical standpoints, and would therefore be regarded according to present-day views as more or less of an adulterant. From the point of view of chemical protection, it is of some considerable value. This is due rather to the more inert character of the bitumen than to any chemical combination between the bitumen and the rubber. When bitumen is used as a sheath there is no mutual action between the bitumen and the rubber, the bitumen merely acting as a non-hygroscopic layer of protective material. As stated in the paper, vulcanized bitumen is remarkably inert to atmospheric and purely chemical action, and this statement can hardly be said to apply to rubber, although if specially designed for this purpose the degree to which rubber can be made to resist such actions may be much improved as compared with rubber made specially to fulfil other conditions. There is a parallel case in soaps.

Mr. Mitchell's remarks as to practical limits of cable dimensions appear generally to coincide with the views expressed in the paper. With regard to the maximum size of conductor for a working pressure of 30 kilovolts, I think it will be found in practice that from the economical loading aspect the best results will be obtained from sizes less than 0·25 square inch, or even 0·2 square inch, and that therefore no great difficulties will arise which will entail short draw-lengths. The question of increasing the working pressure on existing cables from 11 kilovolts to 20 kilovolts is merely one of factors of safety, but as mentioned in my reply to Mr. Vernier,* care should be taken to ensure that all probable sources of weakness are dealt with before the change-over is made.

Mr. Mitchell's joint, with cast-lead ends on a cast-iron sleeve, is excellent, but in my experience there is—with present-day workmanship — little or no trouble with ordinary wiped joints on cast-lead sleeves. The chief trouble, with sleeves made from sheet or tube lead, used to arise from imperfections in dressing down the ends of the sleeve to fit the lead sheath of the cable. The difficulty of making this reduction in diameter with comparatively thin lead caused a tendency for folds or pleats to be formed, over which it was practically impossible to wipe efficiently. Consequently, minute channels through the wipe were left for water to creep through, and to this many faults have been traceable. The more substantial cast-lead sleeve with ends already shaped so that little dressing-down is required in order to fit them to the cable has overcome the trouble.

I am glad to have Mr. Mitchell's approval of the cable-joint details described and illustrated in the paper, especially with regard to the elimination of fibrous wrappings. His conclusion, however, that appreciable force is required in order to get the porcelain spacers into position, is quite wrong. In fact, the spacer is expressly designed to avoid disturbance of the joint and core insulation. The centre web is slipped sideways between the cores and then turned at right angles ready to receive the outer rings which have been previously threaded over the cable ends before jointing. A slight turn of the ring locks the two parts of the spacer together. The short length of the spacer—it is practically a disc—and its curved surfaces reduce the danger of air traps to a minimum. Anything in the form of an insulating sleeve has the disadvantage of having to be placed in position over the core or cores before the conductor joints are made. It then has to be drawn along the core or cores into its correct position, and as the cores in a 3-core joint must be more or less bowed, there is a danger of disturbing the paper insulation, or if loose enough to avoid this, there is the alternative risk of trapping air in the annulus between the core and the sleeve.

With reference to Mr. Mitchell's remarks on rubber, I would point out that no objection is raised in the paper to mechanical and other tests. My point is that such tests, unless grouped with other tests of suitable character and severity, do not give results which are necessarily a criterion of electrical value or durability. Mr. Mitchell is apparently under a misapprehension with regard to the statements in the paper on the appearance of tinned copper conductors after vulcanization. It was intended to convey that silvery brightness of the tin coating after vulcanization might usually be taken to cast suspicion on the quality of the rubber. It has nothing to do with the purity of the tin or its application to the wire. A low-grade foreign wire may often be detected by an expert eye by this feature alone, the chief connection between low-grade rubber insulation and the silvery whiteness being that, during the vulcanization of the rubber, acid products—due to the method of preparation of the "pure" rubber layer, or to reactions brought about in organic (loading)

* Page 364.

[illegible] corresponds very closely to my description above referred [illegible]

Mr. [illegible] Nisbett on the breakdown of cables having small conductors, as compared with those having large conductors, simply amounts to a matter of discrepancy between the law relating to the ideal cable—having an isotropic [illegible] expressed my belief that given exactly comparable con- [illegible]

[illegible] under mechanical stress and that of the dissociation of [illegible] to know that Mr. Stevenson's experience in cases of [illegible] conditions, yet the softening was sharply confined to the vicinity of the fault.

Mr. [illegible] (Newcastle discussion).[illegible]

DISCUSSION ON

"Automatic Protective Switchgear for Alternating-current Systems." *

Yorkshire Local Section, 13 January, 1915.

Mr. Shaw. Mr. J. H. Shaw: At Bradford we use the Merz-Price gear for protecting three generators, and in one instance it saved an interruption of the supply. A 4,000 kw. high-tension machine broke down to earth, and the Merz-Price gear disconnected it practically instantaneously, without affecting the supply at all, the other machines which were running in parallel with it sharing the load. I should like to ask the author, however, if he does not think it advisable to put an interlock on the protective gear so that if the relay operates from any cause the field switch or the field circuit is opened. After the above-mentioned experience we obtained various estimates regarding the length of time that the field was left on after the fault; the estimates varied from 1½ seconds to 10 seconds, but by that time the generator was a mass of flames and the windings were practically destroyed. I should think some means could be devised so that, if the relay operated, the field circuit would be opened, but that if the oil switch was opened by hand the field could remain on. In connection with the protection of generators, we have one set of Merz-Price gear which has only three pilot wires, the neutral points of the relays being earthed. Originally the three neutral points of the two sets of transformers and the neutral points of the relays were earthed. On test it was found that the relays would sometimes operate during synchronizing. We then removed two earth connections and the installation has since behaved perfectly. We are now informed that if we were to get a heavy fault on a high-tension feeder near the works the relay would operate. We have had one or two faults and have endeavoured to produce the conditions of a heavy fault, but we have never made the relay operate. For protection against faults on high-tension feeders we have relied up to now solely on inverse time-limit overload and leakage relays. We had reverse-current relays, but we found that if the voltage on the system dropped suddenly from any cause the reverse-current relays operated and isolated healthy sections. Our greatest difficulty with overload and leakage relays has been to obtain a satisfactory instrument; only a short time ago we sent out an enquiry for a number of leakage relays with varying time elements, but we could not get a satisfactory quotation from any English manufacturer. When purchasing induction-type relays we generally specify the longest time-lag and the minimum lag under short-circuit conditions, that is to say, the time when the curve becomes parallel with the base. Many manufacturers' ideas of accuracy of time and our test-room ideas are very different. I have known a relay travel between the manufacturer and ourselves three times before we were satisfied. I should like to ask whether it is possible to make a relay (I believe this has been mentioned in American practice) that is perfectly synchronous when a certain amount of current is passed through its coils, but furnished with a second winding as a shunt to the main windings in order to make the relay dead-beat, so that it is possible to get rid of the uncertain period of time generally allowed in setting overload devices for the over-running of the relay. An addition of a few pounds to the cost of a relay controlling perhaps a 2,000 or 3,000 kw. feeder is not very important. Again, referring to the time limit of relays, a few years ago our feeder overload relays in the generating station had minimum time settings of two seconds on short-circuits. When a high-tension feeder fault occurred practically all the synchronous machines dropped out of step; we then decreased the time-lags to a minimum of 0·8 second under short-circuit conditions and since then we have been able to "clear" fairly heavy faults quite satisfactorily. The methods of connections shown in Figs. 6, 7, and 8 are most attractive, but it must be remembered that they involve carrying a fourth or neutral lead right up close to the oil switch if it is desired to protect the cables, current transformers, etc., in addition to the windings of the generators. I should be glad if the author would say whether it would be possible to design a transformer if separate lead-covered paper-insulated cables were used for each phase. We find on our latest machines that it is advisable to do this, and I suggest using 0·5 sq. in. lead-covered paper-insulated cables. I should think such a transformer would be almost impossible. On page 162, dealing with the protection of parallel feeders, the balanced overload relay shown and described is very interesting, but it appears that if No. 1 feeder were accidentally disconnected some special provision would have to be made to prevent the switch of No. 2 feeder also dropping out. The split-conductor system is very attractive, and since reading the paper I have looked up our records of high-tension faults. With 50 miles of 3-core 6,600-volt cable in service we have had six faults in 10 years, none of them due to natural causes such as bad plumbing or bad jointing. We have had four faults due to road contractors driving picks and crowbars into the cable. If a navvy can drive a wedge through the concrete and fibre ducts and into the cable I hardly think he will hit the outer conductor and not get into the inner conductor, and in my opinion the possible difference of resistance between a crowbar's contact with the inner and outer conductors is unlikely to be sufficient to operate the relay.

Mr. Selvey. Mr. W. M. Selvey: This paper deals with a branch of power-supply work the details of which have not come largely into my personal experience, although I have grown up, so to speak, in the home of protective devices. I was interested in the early lay-out of the cable systems in the North. At that time our great difficulty was to get a reliable reverse-current relay which operated with not more than 10 per cent reverse current, but those difficulties seem now to have been overcome. The author says that relays can now be made to operate with 3 per cent reverse current, and the low-voltage effect is overcome by making them unstable, so that satisfactory operation is obtained even when the voltage is low or practically zero. It was

* Paper by Mr. E. B. Wedmore (see p. 157).

[illegible] certain point, and then difficulties arose, to which the [illegible] is, I believe, capable of such fine setting that it is impossible for that state of affairs to occur. In that respect it is an advance in protective gear. The question [illegible] the supply for a short time means, say, shutting down the ventilation of a colliery, it becomes increasingly important to have a duplicate supply for that colliery arranged in such a way that a faulty feeder which causes failure of the [illegible] necessity. As the introduction of any new apparatus invariably means additional points to be looked after, protective gear no doubt in the early days caused a certain amount of tripping of switches, due to small faults in the [illegible] system, and such troubles are very soon overcome. I think we cannot afford to do without these devices, and those engineers to-day who are able to show such a [illegible]did record as Mr. Shaw has given, may in the future, when their systems are of the size that their energies [illegible]

Mr. W. B. [illegible] whether he considers it quite satisfactory to adopt that form of protection where there are existing 3-core cables, and how the method would compare with the proposed 6-core cable. From the point of view of simplicity the [illegible] cable that is known from experience to be satisfactory. I [illegible] wave form? Where one [illegible] if the wires in an overhead line are accidentally connected [illegible] as I can see, without calling attention to this. The ideal protective device is self-checking, and the split conductor does not seem to be self-checking against that kind of [illegible] before us very clearly, and suggested a protection which [illegible] practical difficulties in the split-conductor method they will be surmounted.

Mr. W. L. [illegible] think this paper is very opportune. In the fourth paragraph [illegible] grown to five times its present dimensions, there are likely [illegible] results of individual faults are likely to be far more serious," will be much more cheering to the gas industry than to the central-station engineer. It might be true if the whole [illegible] points in the paper, I was very interested in the remarks on the reverse-current relay. This was considered a very promising device at first, but later proved very disappointing [illegible] practical experience, up to the [illegible] this field is very limited, and that for most purposes of protection one or other of the alternatives will give better [illegible]

is a strong testimonial to the workmanship and materials employed, as well as to the principle itself. It means the very best of all three to get the results that are actually obtained, without introducing much more trouble than the arrangement avoids. On the split-conductor system the same point occurs to me as to Mr. Woodhouse; if two wires touch, which might easily occur with the overhead arrangement, the remainder of the line would be left without this protection. The next point that I want to emphasize is in connection with the oil switch on which all these protective gears act. I question whether the oil switch has not reached its limit, in large generating stations at any rate. Generators rated at 30,000 kilowatts are already in use, and larger are to follow; and although reactive coils may be put in the circuit in order to protect the generators, these do not equally protect the switch, as although they reduce the current, reactance is particularly liable to maintain an arc, owing to its increasing the stored electromagnetic energy, nearly all the latter being released in the switch at the moment of opening the circuit. If a really "dead" short-circuit occurs on one of these extra large generators, which might happen through the action of lightning or faulty material, I doubt if any existing oil switch actuated by one of the instantaneous devices described in the paper would open the circuit without the switch being practically destroyed. To strengthen the switch casing is no remedy, since the mechanical pressure exerted by the vaporized oil at the temperature of the arc is too much to expect any case to hold. It simply means that the stronger the case, the bigger is the explosion when the case gives way. This inability of the oil switch to absorb a very large amount of energy without serious destructive action seems to me a serious limitation of that type of switch, and I think the remedy is, not to surround the switch contacts by oil, but to use a slightly conducting fluid of high specific heat capacity, such as water. The fundamental defect with oil is that being an insulator it does not absorb the energy liberated on opening the switch, with the result that this energy is concentrated along the direct path of the arc, with the maximum destructive action. A high-resistance fluid such as water would shunt the arc, and through its combined cooling action and effective shunting of the current would greatly reduce the destructive effect, and would absorb quietly the energy that is liberated from an inductive circuit even at zero point on the voltage wave when the circuit is broken. The great heat capacity of water is of great assistance in this respect, and the fear of any explosive effect from the small amount of water decomposed is without foundation, as the gases generated by the arc are at a higher temperature than that at which they recombine, so that they recombine quietly without shock. I remember an incident over 20 years ago with the old Brush switch-columns which had a water-break switch in a glass cylinder on the top. It was not a very well-balanced design, having a heavy slow switch movement with a very weak stop for the "on" and "off" positions. The handle had to move through 180° from "on" to "off," or vice versa, but one day having made a very bad synchronize, and the incoming machine failing to pull into step, the engineer pulled the switch out so violently that it broke the stop and the switch handle made a complete revolution reconnecting the machine 180° out of phase. He repeated the process in the reverse direction before finally keeping the switch in the "off" position. The switch, however, stood this treatment well without disturbance, in spite of the slow moving contacts and the Mordey alternators with ironless armatures, which gave enormous short-circuit currents like those with a modern turbo-alternator. I consider that not only the oil switch, but also its arrangement on switch-boards of modern design, is unsatisfactory from the design point of view. In some of the largest generating stations where all the main cables are concentrated at one end at the back of the switchboard, there is a row of switches with many hundreds of gallons of oil. The switches themselves will probably some day fail, either as the result of an internal fault or owing to abnormal external conditions such as lightning trouble or a "dead" short-circuit. In addition to this large volume of quickly-spreading inflammable material, there is an almost unlimited supply of power in the cables and a network of pilot and relay wires that will be fused and spread trouble when the main current reaches them. I think it would require considerable ingenuity to devise a combination better adapted to cause a disaster of the first magnitude, so far as the generating station is concerned, than this modern arrangement. A fault on the generator probably shuts down only that generator, but a well-developed switchboard fire, with the amount of oil now used, is sufficient to shut down the whole station for a considerable period. The remedy for that I should say would be to discard all the present switchgear, use a non-inflammable slightly-conducting fluid instead of oil round the switch contacts (if water is used its great heat capacity is a further advantage), have the control platform well away from the switches, with no pilot wires or electrical connection between, and utilize pneumatic control through insulating tubes. It is possible that pneumatic relays might be used instead of electrical relays in connection with the switch trip coils, with a gain in safety, since all these light wires, like metallic veins, are a source of weakness. On the question of simplicity I think there would also be a gain, but of course this is a claim made indiscriminately for all these appliances, and in the absence of a definition and standard of simplicity it is a matter usually open for debate. If the Engineering Standards Committee would publish such a definition and standard, the position in this respect would be much clearer. Taking the arrangements described in the paper, I can conceive an engineer confronted with a complete diagram of a supply system, say from the generators to the consumers' side of the transformers, fully "simplified" in accordance with the recommendations—split-conductor feeders, circulating-current protection for the transformers, triplicating these by the addition of the two additional small ones, and with pilot wires, core-balancing for the open-circuit feeders, again more transformers, trip coils, and secondary pilot wires—asking to see something complicated before he could appreciate the full simplicity of it all. However, in spite of all this "multiplied simplicity," which seems to me very far from finality, I think the balance is on the right side, that the author's claim is justified, and that if the devices which he has described are properly utilized, in the manner recommended at the end of the paper, a degree of protection is obtained which has hitherto been unattainable.

Mr. H. H. WRIGHT: This paper should prove useful,

[illegible]

Mr. A. R. [illegible] [illegible] circuit current, and they rely upon the other machines sending enough current into the faulty one to operate the [illegible] tioned that current [illegible] think that the percentage [illegible] [illegible] es on this feeder tripped [illegible] network; no fault was found with the protective gear on this sound feeder, and so far as I could see the tripping of the switches was due to the fact that the [illegible] transformers at one end were in a cellular type [illegible] frost, it is almost certain that the two wires would be coated with ice and frozen together for practically their whole length, and if this did not cause a short-circuit on the split conductors, there is the further possibility that the [illegible] of the two wires, horizontally, is a favourable one [illegible] [illegible] aking both conductors in one span and causing an open circuit in both conductors at the same time. Furthermore, one cannot be positive that the fallen wires would make a sufficiently good earth connection, lying as they might do for perhaps a few feet in snow, [illegible] system. In connection with the concentric arrangement of the duplicate conductors for underground cables, the author states that the cost of this cable system is very little greater than the cost of one of equal conductivity of the [illegible] were greater possibilities of trouble from [illegible] of 3-core single conductor. Another point that has not been mentioned is the advantage of being able to do without automatic tripping devices for switchgear. I believe I am right in saying that one of the largest power [illegible] opinion this is the ideal system of protection from a continuity supply point of view, and when combined with [illegible]

[illegible] that was actually the case I cannot say, but the protective [illegible] feeder. The split-conductor system is practically quite new to me, but I should imagine it is a great advantage over the Merz-Price gear, which employs a pilot wire, as undoubtedly the latter is a great nuisance, [illegible] run overhead, though I believe that the [illegible] by the lead cracking due to [illegible] cable to swing in the air have [illegible]

Mr. T. [illegible] country, I think the electrical industry is [illegible] inventing and perfecting automatic devices for the [illegible]

Mr. Roles. especially heavy alternating-current switchgear. Mr. Shaw has referred to our experiences in Bradford. I think that the Bradford station was one of the first in which the Merz-Price gear was installed for the protection of generators. We had seen that this gear had been successfully used for feeder protection, and when installing our first turbo-generators—two sets each rated at about 4,500 kilowatts—we had under consideration various methods for the protection of the generator windings and cables, more especially the cables between the machines and the switchboard, each cable being something like 200 yards in length, since the generators are in a building remote from that housing the switchboard. We could hardly follow the method suggested by one speaker in this discussion, viz. to use an overload device, as we had specified that the generators were to withstand a "dead" short-circuit for a period of three minutes. We finally came to the conclusion that probably the Merz-Price gear would meet our requirements, and it is gratifying to know that it has done so. In the early days of its use the gear operated on one or two occasions for no apparent cause, but fortunately no inconvenience was experienced as a result. Steps have since been taken to prevent such occurrences, and for a considerable time past the gear has proved in every way satisfactory. It has already been mentioned that on at least one occasion the gear has prevented a total shut-down of the supply—this, of course, being the main object of its installation—although it was not capable of saving the generator, which was entirely burnt out, the fire obtaining too strong a hold before the field circuit could be broken. I have always regarded automatic devices as almost certain sources of trouble, and I have, where possible, avoided using them, but now that transmission and distribution systems are attaining such large dimensions, I am of the opinion that the increasing use of such devices is becoming imperative. In most systems, up to the present, parallel extra-high-tension feeders are, I think, not used to any great extent, but it appears to me that in future there is a probability of parallel feeders being more extensively utilized. When recently perusing the description that has been published of the new Manchester generating station, I noticed that, in addition to putting down a new power station, a distributing station is to be provided apparently as near as possible to the centre of Manchester, and in that case I take it that there will be a number of parallel feeders, and also that these feeders will be connected to busbars at each end. If that is not done, very complicated selector devices will be necessary at the distributing station in order that the load may be shared by the feeders as equally as possible; but if the feeders can be connected to busbars at each end there is the advantage of a considerable saving in copper being effected, and that the voltage-drop between the generating works and the distributing station is the same on each of the parallel feeders at all loads. In such a case it seems absolutely necessary that some automatic protective device should be used, otherwise a large supply system like that of Manchester might be entirely dislocated. The use of such automatic devices seems to have more or less settled the question, which was very much debated at one time, whether to earth the neutral point of 3-phase systems at the generating stations. From what I can learn, the engineers responsible for systems which were originally started without an earthed neutral have one by one changed their views, and now in practically all cases the neutral of at least one machine connected to the busbars is earthed through a suitable resistance.

Mr. Wedmore. Mr. E. B. WEDMORE (*in reply*): Mr. Shaw has recommended the employment of automatic field switches in conjunction with large alternators, and I heartily support that recommendation. The automatic features should be such that the field switch remains closed if the oil switch does not open; also on the oil switch being opened the field switch should not open unless the protective relay has operated; otherwise, in the first case there is danger of a machine being left on the system without any field, and in the second case it would be impossible to take a machine off the busbars without making it "dead." It is not quite clear to me what arrangement of connections was in use which gave the trouble referred to by Mr. Shaw. There are several practical details in the design and arrangement of the apparatus not covered by the paper, but the arrangement shown in Fig. 17 is quite satisfactory. Mr. Shaw emphasizes an important point in the construction of time-limit relays designed to give discriminating action by the grading of the time settings. I refer to the necessity of taking account of the time required by the moving parts of the relay to cease movement after the circuit is opened. This feature is mentioned in the paper, but has been very generally overlooked in the design of this class of apparatus. The present price of a triple-pole time-limit relay is about £9, and I consider it to be impossible to build a relay at this price which would possess all the desirable characteristics referred to. The market for protective apparatus has been spoiled by the introduction of a number of inferior and ill-designed devices, and it is good to know that there are engineers who are willing to pay a reasonable price for a sound article.

For the protection of sources of supply, such as generators with three single-core cables, it is not essential to use the type of protective transformer shown in Fig. 8; an arrangement similar to Fig. 5 can be applied equally well, and whilst the three line transformers can be mounted near the switchboard, thus protecting the cables as well as the machine, the fourth transformer can be mounted in the earth connection quite near the machine. So it will be seen that it is unnecessary to bring up to the switchboard a fourth heavy conductor.

Mr. Shaw has anticipated some difficulty in connection with the interlocked feeder system shown in Fig. 11. I should explain that auxiliary switches which change over the connections when the oil switch opens are so arranged that they complete their work whilst the switch contacts are still in contact. There is an overlap on the oil switch contacts of one inch or more, and it is during this part of the stroke that the auxiliary switch operates; thus there is no difficulty in putting feeders in and out of service at any time. Mr. Shaw has had very satisfactory experience with his feeders, and other speakers also suggest that modern experience indicates that feeder faults are becoming a relatively negligible factor. It would be a great mistake, however, to conclude from this that feeder protective gear is becoming less necessary. Feeder protective gear would be correctly described as "apparatus for the protection of shareholders and consumers." If no feeder protective gear

[illegible] will grow at least p[illegible]

[illegible] stations in prospect having an output exceeding 100,000 [illegible]

[illegible] flexibility, and the experience with it in practice so far has been very good and promises better results than are obtained with the usual type of joint.

[illegible] where there is a sufficient number of feeders available to enable them to be paired and cut out in pairs on faults occurring. This case arises where there are a [illegible] distributing centre or tying stations together, or where a ring main is duplicated to obtain the necessary [illegible]

[illegible] system requires the provision of an enormous number of switches which cannot be purchased at a reasonable price if they each have to withstand "dead" short-circuits on a [illegible]

[illegible] rash man who would start in 1915 to install a 100,000 kw. plant with novel designs in oil switches and control [illegible]

[illegible] in wave-form will have on the protective devices recommended. Variation in wave-form has no effect on any of the apparatus recommended, and this should have [illegible] apparatus. In the particular case of Merz-Price apparatus, the currents compared at the two ends of the line are one and the same current and will vary together. [illegible] characteristics of the two halves are carefully balanced [illegible]

From the point of view of the mains engineer, it has [illegible]

Trouble has been anticipated due to snow settling on split-conductor overhead lines and due to lines touching one another. Some speakers think that more trouble will ensue than with single lines, and others less. [illegible]

[illegible] in faulty feeders until the fault has been developed to an [illegible]

Mr. Wedmore if necessary in such circumstances. Such a course would not have been dreamed of with the older types of protective apparatus.

It has been mentioned that where the interlocked feeder system is employed the apparatus will not discriminate correctly in case a feeder becomes open-circuited. This criticism is quite sound, but it will be recognized that such faults are few and far between. On the occurrence of such a fault and on the sound feeder being disconnected the faulty feeder is at least as well protected as would be the case under any of the older systems, and even should it fail between phases, causing a severe shock to the system, one has the great advantage that other sound feeders on the system are held up to their work, whilst with the older protective systems such a fault would generally cause an extensive shut-down.

Newcastle Local Section, 18 January, 1915.

Mr. Porter Mr. G. L. Porter: This paper gives a great deal of very up-to-date information regarding protective gear, including the split-conductor system. The local power companies have now had considerable experience with this system and it has been tested several times by having heavy fault currents through healthy feeders, with results in every way satisfactory. Our experience is of course mainly with the reactance current-transformer type of gear shown in Figs. 24–26, and the split-switch arrangement has really yet to prove itself. Every form of apparatus has its own particular disadvantages and there are certain inconveniences resulting from the adoption of split-conductor gear. I do not know Mr. Vernier's opinion of the concentric cable, but the necessary transposition in the joints is to my mind unfortunate. Suppose there is a cable running between two sub-stations with the "splits" transposed so as to give equal lengths inner and outer, and it becomes necessary to loop into a new intermediate sub-station, four joints might be required instead of two in order to get the transposition right. Also nowadays we find it necessary to install regulators at various points on a large system, and with other forms of protective gear we protect a regulator by including it with the feeder inside the feeder protection, but with the split-conductor system it is necessary to have separate protection for the regulator and to introduce a switch between it and the feeder. In the ideal combination of apparatus given at the end of the paper, we are told that for all closed feeder circuits the split-conductor system is the correct one. However, on short underground feeders the Merz-Price system will certainly be cheaper and the lighter fault settings of the split-conductor unnecessary. For overhead lines, of course, there is no comparison, as a light fault setting is a vital matter where an overhead line can come down on dry ground and the fault current be thereby limited. The split-conductor system has also the advantage that with a moderate load on the line the breaking of the conductor before its fall will trip the switches. I am afraid that in this climate trouble may be experienced with the arrangement of overhead line mentioned below Fig. 28, as I should expect two conductors so close together to gather more than twice as much weight of snow as each would separately. In his list of advantages of "the ideal combination of apparatus," the author states that all the devices are instantaneous in operation. However, our experience of the balanced-current protection of transformers is that a time-limit device should be used on account of the momentary rush of current when switching on. This time-limit device enables us to run with a much lower fault setting. Then with modern arrangements of power stations, the switchgear is often remote from the generators and the long lengths of pilot cable for the generator protection necessitate the introduction of resistances in order to bring the equipotential points to which the relays are to be connected back from the middle of the pilot cable to the relay position. A small fuse in parallel with the relay will probably make these resistances unnecessary, as the time limit of the fuse will prevent the out-of-balance due to the pilot resistance from tripping the relay during the momentary excessive rush of current from the generator when an outside short-circuit first occurs. Generator protection is an interesting problem. Reverse-current relays are supposed to "clear" a machine which has lost its field; but if only two machines are running at the time, the one on which the field has failed will merely give out a wattless leading current and the reverse-current relay will not act. Even, however, where a large number of machines are running at once—as at Carville—we prefer to use simple overload gear set above the short-circuit current of the generator, so that no machine can trip itself out, but the healthy machines can jointly clear a faulty one. The lower settings that can be got with balanced protective gear sound attractive from the point of view of saving damage to the machine, but, however quickly the switch opens, the generator can damage itself quite as much. I notice that in the generator protection shown in Fig. 17 overload fuses are included. Surely if discriminating protective gear is used these are unnecessary, as, rather than risk the generator tripping out when sound, these fuses would normally be set for a value above the short-circuit current.

Mr. Vernier Mr. C. Vernier: In the previous discussion* several points have been raised in connection with split-conductor cables upon which I should like to make a few remarks, having had considerable experience of this type of cable. The first question is the fear expressed that what the author has called a "relatively light" insulation between "splits" may not be sufficient to withstand the pressure without breaking down in the event of one split being earthed and not the other. I think this doubt can only arise from lack of experience of what the insulation of cables will stand. I have on several occasions called attention to the large factors of safety on cables constructed to the Engineering Standard Committee's thicknesses of insulation, and this is a very good illustration of what I had in mind. The usual thickness of insulation between split conductors is between 0·08 inch and 0·10 inch. I have seen a pressure of over 20,000 volts applied to 0·10 in. insulation between "splits" for over an hour without breakdown, and quite a usual test after laying and jointing on these cables is 10,000 volts for 5 minutes. These figures really give us a true indication of the pressure that this thickness of insulation will stand for very short periods

* Page 169.

[illegible] reduce the thickness of insulation between cores and to [illegible] the ordinary circular core for the same test [illegible] split-conductor cables for all sizes and voltages. I think it correct to say that if the cores can be split into an oval concentric type of cable one can always construct a [illegible] core than with the ordinary construction of cable. There is a limit of sectional area of core for ordinary e.h.t. cables [illegible] which it is not advisable to go on account of [illegible] upon the insulation, and other reasons. [illegible] put down at not less than 0·05 square inch, and although cables of this size have not, I believe, hitherto been constructed of the oval concentric split-[illegible] especially if the principle of inequality of split conductors [illegible] ting oval concentric split conduc-[illegible] much more apparent than real. The type of joint used is illustrated in Fig. C on page 357,* and while at first sight this may appear very complicated and difficult to make, it is quite easily done in practice, and no difficulty has been experienced in getting jointers to undertake it satisfactorily. [illegible] use. With regard to the question of the cost of split-conductor cables as compared with Merz-Price gear, the split-conductor cables are in all cases cheaper than an ordinary cable with a pilot cable. The further advantage is obtained of dispensing with the maintenance of one cable, which in the case of small cables, such as pilot cables, is usually much heavier than on large cables. A further saving can be obtained in connection with way-

* [illegible]

[illegible] larger development of electric [illegible] is absolutely correct to say that without it the great [illegible] made in this district would not have been [illegible] thing like the same scale. In my [illegible] a marked improvement upon the Merz-Price [illegible] with a [illegible] pilot cable, can be set to trip at [illegible] lower currents, and in the case of overhead wires will cut out a line without an earth fault being necessary; that is to [illegible] able condition for the gear to operate. In this connection it may be mentioned that the Board of Trade are quite [illegible] catch-guards on overhead lines where this type of protec-[illegible] to any other type of [illegible] upon an earth current for its operation. Finally, the Merz-[illegible] especially the latter, in the rapidity with which a fault is cut out. We have a few overload devices, and we seldom fail to know when a fault has occurred on these particular feeders because this frequently breaks down some other [illegible] high values. In support of this, I may say that it is becoming quite a common experience to have to apply test pressures to cables which have broken down owing to the impossibility of locating the faults which are of very high resistance. From the mains engineer's point of view [illegible]

Mr. [illegible] Press and in Patent Specifications it has been in a scattered [illegible]

from the point of view of maximum load but from the number of consumers supplied from a single network. I think therefore that the function of this Local Section should not be to criticize the paper but rather to confirm from our actual experience the recommendations that the author makes. All concerned in the operation of the North-east Coast network will agree that its commercial success is largely due to the foresight of its designers in realizing the possibilities of proper protective gear. It is often assumed that protective gear is such a live question on the North-east Coast because of the interconnected network. It is rather the reverse; the network owes its existence to the fact that protective gear was studied and developed here commercially some years in advance of its practical value being realized elsewhere. The key-note of successful design in protective gear is referred to in the paper, but it is so important that it will bear repeating. It is not a difficult matter to ensure that the faulty apparatus shall be isolated; the difficulty rather lies in ensuring that sound apparatus is not affected by the passage of heavy short-circuit currents caused by external faults, and it is in compliance with this essential point that the systems recommended by the author have proved successful. With regard to the protection of independent feeders by the core-balance system, I notice that no reference is made to the saving of high-tension switchgear at the far end; this seems to me to be one of the chief justifications for using the somewhat imperfect protection afforded by the core balance method. In this connection it may be pointed out that in the case of a duplicate supply with two feeders and two transformers all high-tension switchgear at the consumer's end can be dispensed with by connecting one transformer to each feeder and protecting both feeders by the core-balance system. This is permissible because the transformers are only paralleled on the low-tension side, and thus any high-tension earth fault on one feeder or transformer does not affect the protective gear on the other one. Arrangements have of course to be made so as to trip the transformer low-tension switch in case the corresponding high-tension switch at the other end is tripped; this can be usually managed by using a core of the telephone cable. One difficulty which the author does not mention in regard to the protection of an independent feeder is that one can seldom be quite certain that it may not be desirable at a later date to link it up with other parts of the system. Unless the length is very short it is therefore often desirable to put in suitable cable so that it can be used as an interconnector at a later date. The disadvantages of the reverse-current relay are pointed out very clearly, but there is the further disadvantage that it necessitates the use of a potential transformer, which is a very untrustworthy type of apparatus and should not be installed except where absolutely necessary. In the description of the split-conductor system there are two advantages that are not mentioned. The first is that the two currents are balanced directly against each other without the intervention of any current transformers or similar apparatus, the balance of which may be upset by rough usage or heavy loads. The second is that this system is equally if not more suitable for very long feeders than for feeders of ordinary length, whereas with Merz-Price protection it is difficult to get a satisfactory protection above a certain length of feeder owing to the capacity current in the pilot wires. I think transformer protection is the one matter dealt with in the paper for which the apparatus now available is not perfectly satisfactory. As mentioned by Mr. Porter, the balanced protective gear has to be set fairly high and with a time limit in order to deal with current rushes on switching in and with the tappings which are usually provided for varying the transformer voltage; this makes it difficult to cut out at an early stage faults between turns, which are a frequent cause of transformer breakdowns. Referring to Fig. 12, I should like to know whether the balanced protective relay is mechanically as well as electrically biased, as otherwise it would seem to be unstable at no load. In Fig. 18 I notice that the secondary wiring is shown earthed in two places. It may be safe to have two earths with this particular arrangement, but as a general rule in all Merz-Price systems it is important to make the earth connection at one point only. Mr. Beard

Mr. H. W. CLOTHIER*: I wish the author had added a T-connection to one of the ring mains shown in Fig. 1. He has shown a T-connection on an open-ended feeder (or, as it is sometimes called, a "tail end"), but on some large power transmission systems it is found necessary to take tappings from a ring main into the consumers' premises. I admit that a loop is more satisfactory, especially when considered from the point of view of automatic protection, but it is not always possible to loop in, and as "tees" on ring mains therefore seem inevitable, the diagram representing "the elements of a distribution system" is incomplete without them, and the design of the controlling apparatus is not ideal in every respect unless it provides for their protection. The author's statements about leakage protection of the core-balance type and its bearing upon the problem of earthing and the amount of resistance required at the neutral, are well chosen and opportune. I hope that they will have the effect of reviving this useful and simple adjunct to the better-known systems of overload protection. I know of a few installations, mainly in mines, on which the method has been applied to advantage, but I believe it has not been appreciated as a feeder protection on large systems, in fact I have reason to think that its full value was not realized even by those at whose instigation it was investigated and developed some six years ago. I endorse the author's remarks about reverse-current relays, and the frequency with which they appear in published specifications is sometimes surprising to me. As to parallel feeder protection, I am not impressed with the author's design of plunger balancing relay. I have not seen it in practical form but I should expect to find mechanical difficulties in the balance of the rocking levers if the latter are constructed as shown on the diagrams, and the main parts seem to me to be rather too heavy for sensitive adjustment. I would prefer an electrical balancing arrangement between a movable and a fixed coil or coils. There are three disadvantages to parallel feeder protective systems which occur to me and are not emphasized by the author, viz.—(1) The wrong switch will be opened when the fault is in the nature of an open circuit, for instance a falling line or a drawn-out cable joint, because in these cases the sound feeder takes the greater Mr. Clothier

* These remarks include also Mr. Clothier's contribution to the discussion before the Institution (see page 173).

[illegible]

Fig. E.

[illegible] but it seems to me that, notwithstanding the difficulties, a [illegible] redeemed by combination with the split-conductor method. Really the latter is the outcome of the former. When [illegible] on a dynamometer-type relay and connecting *a* as the [illegible] swing over to the side through which the greater current passes. In this respect it operates similarly to the author's [illegible] operate correctly, the apparatus [illegible] split-conductor protection and [illegible] ating between the two feeders. I quite agree with the author's conclusions. I regard split-conductor protection of feeders as the only really complete solution. It has all the advantages of the

[illegible]

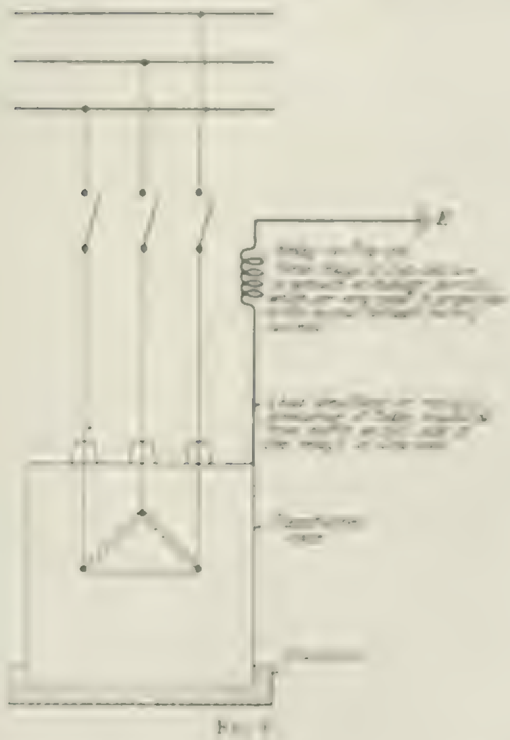


Fig. F.

As a summary of the numerous protective systems the [illegible] former working a relay connected directly in the earth or earthed neutral circuit. There are several of these systems in use, and in some cases the results obtained [illegible] core-balance system that he has described. As notable examples of this alternative method I give two diagrams [illegible]

Mr. Clothier. Merz-Price balanced protective system are somewhat complicated. I notice that the author generally shows direct-operating trip coils (see Figs. 17, 18, 19, and 20), but I have found it advantageous, particularly on large systems, to use relays in preference to such coils. The relays naturally add slightly to the initial expense, but they are a great convenience in that (*a*) a more sensitive fault setting is generally obtained; (*b*) one trip coil suffices instead of three; (*c*) the relay affords a ready means of testing the operation of the switches. Whereas it is easy to trip the relay for testing purposes it is not easy to obtain current through the direct-operating trip coils for this purpose. With further reference to Fig. 20, it seems to me that to split the conductor in a generator winding is an unnecessary complication, and that the ordinary Merz-

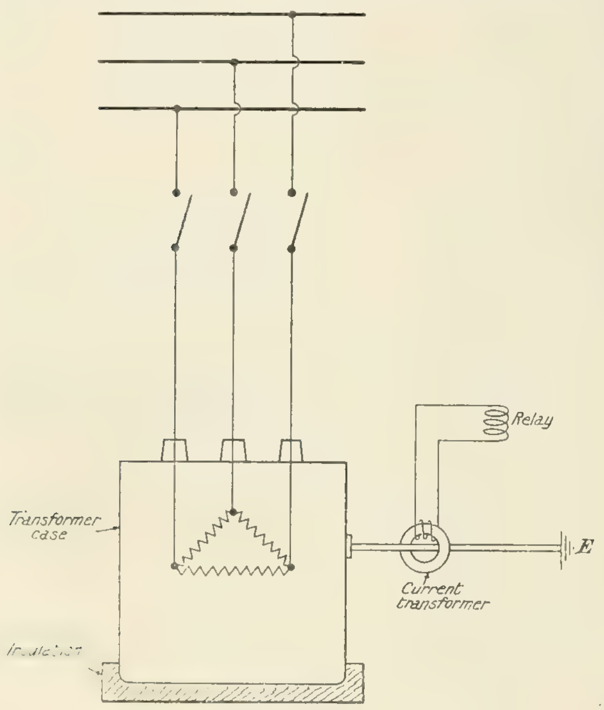


Fig. G.

Price balanced system would serve the purpose of protection covering a transformer and generator just as well. Of course if for the purpose of the generator design it is essential to use two windings in parallel, my objection to this method disappears, but presumably it is not often necessary to construct the generator in this way. The author has described split-conductor protection with impedance-type current transformers, and alternatively with split-conductor switches. I have strong leanings towards the latter method, one reason being that the fault settings can be more easily graded. For instance it is impossible with the impedance-type transformer, without making the transformer unduly bulky, to increase the fault setting afforded by the standard relay, *i.e.* if the normal is designed to trip out with a difference of current in the conductors of 5 amperes the relay must not be set beyond this amount although it may be set below it. With the use of the split switch, however, the setting of the relay may be adjusted to any amount above a predetermined minimum. For example, if the system is designed to trip with a difference of 15 amperes in the conductors, the relays may not be set below this value, but they may be set for anything above it, and by a simple adjustment of the coils it is possible with the same relay to obtain a range of adjustment varying between 15 and 150 amperes. When one considers that at some parts of a large power-transmission system fault currents are much larger than at other parts, it follows that the facilities for adjustment are a great convenience. For example, a short cable near the power station having a doubtful balance may be set for the heavier setting with the certainty of correct operation, whereas an overhead line remote from the power station requires the finer settings in order to ensure its tripping out in the event of a broken line. Under the heading "Other forms of split conductor" the author describes a novel form of split-conductor protection using one conductor with a "fine wire." This system may, as the author describes, be of some value on very small installations, but I should anticipate trouble due to the multiple-turn primary on systems where the amount of power is large. It is a well-known experience on switchgear design that primary turns on current transformers must be of such a section as to withstand, without fusion or distortion, the full stress occasioned by the maximum short-circuit current which the generating plant can produce at the point where the current transformers are used. Normally, of course, this full stress would not come upon the "fine wire" transformer, but in the event of an open-circuit fault on the heavy conductor this exigency might possibly occur. In the construction of switchgear it is essential to forestall if possible all dangerous occurrences, even if they be most remote, and for this reason I would prefer to use the split-conductor protection having conductors of equal section, or at least to avoid using a "fine wire" conductor.

Mr. H. S. Ripley: Whilst dealing with leakage protection the author describes two methods of operation, *i.e.* by utilizing a sensitive relay in conjunction with an auxiliary supply for energizing the trip coil of the switch or by utilizing a trip coil energized directly by the current transformers. In the former case the device can be made to operate on a leak of a few amperes, but in the latter about one-third normal load is the figure given for tripping. Now in some cases, more especially in mining work, it is often inconvenient to provide an auxiliary supply for tripping the switch, but at the same time maximum sensitiveness is required. I should therefore like to ask the author whether it is not possible to obtain a sensitiveness somewhat approaching that obtained with the use of a relay, by employing current transformers of a sufficiently high volt-ampere rating to operate a direct-acting trip coil with a secondary current of about 1 ampere in place of the 3- to 5-ampere trip coils now in general use.

Mr. F. O. Hunt: Most of this apparatus has been introduced since I had anything to do with automatic protective gear, and I should be glad if the author would explain the need for the so-called time-limit fuse shown in Fig. 5. I have recollections of unfortunate experiences with time-limit fuses. In connection with condition 3 on page 161, viz. " . . . and especially on the sudden removal of a fault." I should like to know exactly what the author is thinking of and how the operation takes place.

Mr. E. B. Wedmore (in reply): [illegible] Mr. Porter states that where feeder regulators are employed, it [illegible] It will be found that there is very little objection to the use of fuses in the way referred to by Mr. Porter, and this has been largely done, especially where relays of a rather sensitive type have been used. The use [illegible] and renders any provision for balancing the circuits quite unnecessary. [illegible] fault to earth, whilst it practically disappears on a fault between phases owing to the inverse time characteristic of the fuse. Reverse-current relays suitably designed will disconnect a generator supplying a wattless leading current. We describe them as "failing-field relays." The fuses used with the circulating-current system of generator protection are intended to disconnect a machine in the extreme emergency of a busbar failure or complete failure of an oil switch directly connected to the busbars. The fuse is selected to blow only on a sustained short-circuit, and will not be affected by any faults which are cleared within a second or so by the proper automatic devices.

Mr. Beard has emphasized the point that so-called feeder protective apparatus is not primarily designed for the protection of the feeders, but is employed for the protection of the plant generally and of the consumers' supply. One [illegible] plant without feeder protective apparatus capable of dealing with short-circuits between phases. On a plant of any magnitude experience has shown that unless the protective devices used are discriminating in [illegible] extensive shut-down. It is therefore essential not only to use protective apparatus, but to use protective apparatus which is discriminating in character. This would still be the case even if a cable never broke down; thus it is no answer to say that cable faults are very infrequent with [illegible] further good features in the use of core-balancing apparatus. His remarks refer rather to the problem of the distribution system than to that of the design of protective apparatus. In selecting protective apparatus it is, however, very necessary to [illegible] of the protective apparatus. [illegible]

In reply to Mr. [illegible] only of limited [illegible] Fig. I. [illegible] is applied between this pole and earth and is distributed [illegible] resistance of the coil plus the earth connection is quite small as compared with the resistance of the feeder plus the transformer fault. If one has means for making a really good connection to earth, an arrangement as in [illegible] trip coil or a relay having a number of turns of relatively high impedance. These would constitute a source of danger, and even with an arrangement as in Fig. F there is an appreciable risk involved, seeing that an attendant will assume the case to be dead at all times, whilst it may reach a potential of several hundred volts above earth, either momentarily or for a long period, if everything does not [illegible] in the diagrams. I appreciate that it is easy to test the conditions of the automatic devices where a relay is [illegible] where good supervision cannot be afforded and where [illegible] intended only for use with machines already having a split winding. Machines of large rating for use with "step-up" transformers are, however, now commonly built in this fashion.

[illegible] with the heavy winding under any other conditions than that of a feeder failure accompanied by a failure of the heavy conductor sufficient to force heavy current into the fine winding. The loss of the current transformer in this [illegible] not cause an interruption of supply.

In reply to Mr. Ripley, I would say that in order to get core-balancing apparatus to operate at one-third normal load, it is already necessary to employ a trip coil with a fine-wire winding such as he refers to. It is not commercially practicable to employ direct-acting trip coils operating much below this limit. It should be noted that the volt-amperes output of the current transformers is nearly proportional to the square of the load; thus the energy available for operating tripping devices decreases very rapidly with a reduction of the primary current. A device operating at one-third load will have nearly three times the force available that would be obtained at one-fifth load.

Mr. Hunt asks for particulars of the time-limit fuses shown in Fig. 5 and elsewhere. These fuses are now generally constructed of pure tin wire soldered into heavy terminals on a glass tube; they are carried in spring contacts reinforced with steel backing springs so as to ensure the maintenance of a good contact. The trip coil shunted by the fuse generally carries less than 1 per cent of the current in the circuit. Some trouble was experienced in the early days with imperfect contacts in the fuse circuit, but as now made, and as used for the last eight or ten years, I consider this device is more reliable and uniform in operation than any other form of time-limit overload device. Mr. Hunt asks just what I have in mind in my third comment on reverse-current relays. It will be understood that when a reverse-current relay has to carry a heavy forward current, a very large mechanical force will be produced in the relay. The moving part is generally held against a stop, and exerts considerable force on the stop. Owing to their elasticity, the parts through which the force is transmitted are springs, and consequently a certain amount of energy is stored up in the moving parts; if now the force is suddenly reduced this energy is suddenly liberated, and will cause some movement of the moving parts. There is no difficulty in preventing the relay operating under such conditions if this feature has been properly considered in the design, but relays have been made in which this feature has not been considered, and testimonials have been obtained for clearing faults, which faults were supposed to have sealed themselves after the switches operated, but which, in fact, never existed. Mr. Wedmore.

Several speakers have referred to the question of simplicity in design. It should be recognized that whilst simplicity is a very valuable characteristic, it is a law of Nature that we cannot have differentiation of function without differentiation of anatomical structure. We cannot get new characteristics into our apparatus without making corresponding structural additions. All that we can do is to reduce these additions to their simplest possible form, and this condition has, I believe, been very nearly attained in the devices recommended in the paper.

PROCEEDINGS OF THE INSTITUTION.

ORDINARY MEETING OF 28 JANUARY, 1915.

Proceedings of the 574th Ordinary Meeting of The Institution of Electrical Engineers, held on Thursday, 28 January, 1915—Sir John Snell, President, in the chair.

The minutes of the Ordinary Meeting held on Thursday, 14 January, 1915, were taken as read, and confirmed.

The list of candidates for election and transfer approved by the Council for ballot was taken as read, and was ordered to be suspended in the Hall.

Donations to the *Library* were announced as having been received from A. H. Avery, S. C. Batstone, Messrs. J. H. Bennett & Co., Messrs. J. & A. Churchill, W. R. Cooper, W. Galloway, The Iron and Steel Institute, Dr. A. E. Kennelly, A. P. Lundberg, J. W. Meares, R. Rankin, E. Kilburn Scott, Professor R. Stanley, and A. Still; to the *Museum* from A. H. Allen; to the *Building Fund* from The Association of Municipal Electrical Engineers, R. A. Dawbarn, H. Hirst, Vice-Admiral Sir H. B. Jackson, R.N., K.C.B., K.C.V.O., F.R.S., W. McGeoch, W. G. P. McMuldrow, Professor J. T. Morris, and A. Wright; and to the *Benevolent Fund* from The Executors of the late Augustus Stroh, H. Alabaster, W. Duddell, F.R.S., D. Henriques, E. S. Jacob, H. W. Kolle, W. Murray Morrison, H. Parry, W. R. Rawlings, S. G. Castle Russell, The "25 Club," T. C. T. Walrond, and C. H. Wordingham, to whom the thanks of the meeting were duly accorded.

Professor Andrew Gray, LL.D., F.R.S., Member, then delivered the Sixth Kelvin Lecture, entitled "Lord Kelvin's Work on Gyrostatics" (see page 277).

A Vote of Thanks to the Lecturer was proposed by Professor Silvanus P. Thompson, D.Sc., F.R.S., and seconded by Dr. R. T. Glazebrook, C.B., F.R.S., and the resolution was carried with acclamation.

The meeting adjourned at 9.46 p.m.

ORDINARY MEETING OF 11 FEBRUARY, 1915.

Proceedings of the 575th Ordinary Meeting of The Institution of Electrical Engineers held on Thursday, 11 February, 1915—Sir John Snell, President, in the chair.

The minutes of the Ordinary Meeting held on 28 January, 1915, were taken as read, and confirmed.

Professor G. W. O. Howe, D.Sc., and Mr. W. H. [illegible] were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the result of the ballot was declared as follows:—

ELECTIONS.

Members.
[illegible]
[illegible]
[illegible]

Associate Members.
[illegible]
McLaughlin, Harold Fletcher.

Associate.
[illegible]

Graduates.
[illegible]
[illegible]
[illegible]

Students.
[illegible]
[illegible]
[illegible]
Brocklehurst, Harold John S.
Digby, Harold.
[illegible]

Students—continued.
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]

TRANSFERS.

Associate Member to Member.
[illegible]
Muir, Alexander.
Rankin, Robert.

Graduate to Associate Member.
Baker, Montagu Barrington.
[illegible]

Student to Associate Member.
Edgar, Edward James.
Gay, Henry [illegible].
Sparks, Algernon Charles.
[illegible], Harold Kenneth.

Student to Graduate.
Burns, Sydney.
Hill, Stanley Malcolm.
[illegible], Harold Archibald.

A paper by Professor E. W. Marchant, D.Sc., Member, entitled "Conditions Affecting the Variations in Strength of Wireless Signals" (see page 329), was read and discussed, and the meeting adjourned at 9.55 p.m.

MEMBERS ON MILITARY SERVICE.

(THIRD LIST.*)

Members.

Name.	*Corps, etc.*	*Rank.*
Bridges, W.	4th London (Howitzer) Brigade, R.F.A.	Major
Long, W. F.	Cape Fortress Engineers (R.E.	Captain
Matthews, J. C. M.	Malay States Volunteer Rifles	Corporal
Percy, H. L.	Ceylon Engineer Volunteers	Lieutenant
Pickering, F.	Cape Fortress Engineers (R.E.)	Major
Pigott, R.E.P., C.I.E.	12th Essex Regt.	Major
Williams, C. T.	Northern Signal Service R.E.	Captain

Associate Members.

Name.	*Corps, etc.*	*Rank.*
Baker, W.	Cape Garrison Artillery	Sergeant
Bellamy, L. C. F.	Divisional Engineers, R.N.D.	Sapper
Bollam, C.	Divisional Engineers, R.N.D.	Lieutenant
Booth, J. M. M.	Royal Engineers	2nd Corpl.
Brewis, J. M.	Army Ordnance Department	Lieutenant
Brown, I. C.	Southern Provinces Mounted Rifles	Private
Corbin, E. A.	Malay States Volunteer Rifles	Private
Cornish, V. K.	Lines of Communication, Suez	Chief Electrician
Cuninghame, J.	Bombay Volunteer Artillery	Staff Sergt.
Dalgleish, I. S.	London Electrical Engineers, R.E.	Sapper
Edmonds, C. H. W.	Royal Engineers	Lieutenant
Eustace, S. G. L.	Calcutta Light Horse	Trooper
Gordon, T. I. M.	Penang Volunteers	Private
Harrison, N.	Union of South Africa Defence Force	Major
Henderson, H. W.	Calcutta Port Defence Volunteers	Sapper
Hodgson, A. I.	Hyderabad Volunteer Rifles	2nd Lieut.
Horne, W. J.	Union of South Africa Defence Force	Captain
Houghton, J. W.	Canadian Engineers	Sapper
Kerr, J. A. W.	Transvaal Scottish	Captain
Kerridge, D.	Bengal Nagpur Volunteer Rifles	Private
Laurie, D. S.	Royal Engineers	2nd Lieut.
Macdonald, W. R.	Canadian Naval Service	Lieutenant
MacGregor, W. D.	Bangalore Rifle Volunteers	Captain
Osborne, H. C.	Bombay Volunteer Artillery	Gunner
Peddie, A. M.	Imperial Light Horse	Trooper
Rutherford, J. A.	10th Cheshire Regt.	2nd Lieut.
Sawers, R., Junr.	Kent (Fortress) R.E.	2nd Lieut.
Shannon, J. H.	R.N.V.R.	Sub-Lieut.
Sholl, W. S.	Algoa Rifle Corps	Private
Simpson, A. F. H. S.	Caucasian Cavalry Division, Russian Army	Captain
Speyer, H. R.	Cossipore Artillery	Lieutenant

* See pages 199 and 320.

Associate Members—continued.

Name	*Corps, etc.*	*Rank.*
Sykes, G.	Admiralty Inspector of Aeroplanes and Seaplanes	Warrant Officer
Symmes, H. C.	Witwatersrand Rifles	Captain
Tarleton, W. I.	Cape Fortress Engineers (R.E.)	Sergt.-Major
Trench, A. C.	Royal Engineers	Captain
Vines, C. E.	Royal Artillery	Captain
Vitty, T. H.	London Electrical Engineers, R.E.	Captain
Ward, W. G.	Tyne Electrical Engineers, R.E.	Captain
Webbe, D. B.	B. B. & C. I. Rly. Volunteers	Trooper
Webster, S.	Rangoon Port Defence Volunteers	Sapper
Wyles, J. W.	Bombay Harbour Defence (R.E.)	Corporal

Associates.

Name	*Corps, etc.*	*Rank.*
Annison, A. L.	Divisional Engineers, R.N.D.	2nd Corpl.
Bell, W.	Mussoorie Volunteer Rifles	Lieutenant
Drummond, H. H. J. W.	2nd South-Western Reserve Mounted Brigade	Colonel
Walmsley, A. R.	6th Cheshire Regt.	2nd Lieut.

Graduates.

Name	*Corps, etc.*	*Rank.*
Danson, J. R.	London Scottish	Sergeant
Hollands, E. F.	Union of South Africa Defence Force	Motor Cyclist
Lewis, W. R.	South African Ambulance	2nd Lieut.
Lloyd, J. A.	R.N.V.R.	Sub-Lieut.
Morgan, J.	London Electrical Engineers, R.E.	Sapper
Morris, H.	Cullinan's Horse	Trooper
Patel, N. B. B.	Poona Volunteer Rifle Corps	Private
Pearce, C. W.	Royal Engineers	Sapper
Reay, G. H. N.	7th Worcestershire Regt.	Lieutenant

Students.

Name	*Corps, etc.*	*Rank.*
Baldwin, S. J. W.	Royal Naval Air Service	Petty Officer
Brazel, C. H.	Royal Engineers	2nd Lieut.
Bruce, A. S.	Divisional Engineers, R.N.D.	Sapper
Brunton, T. S.	Bombay Volunteer Artillery	Gunner
Mathieson, D.	Singapore R.E. Volunteers	Sapper
Organ, H. P.	10th York and Lancaster Regt.	2nd Lieut.
Page, J. J.	Royal Field Artillery	2nd Lieut.
Symons, E. J.	London Electrical Engineers, R.E.	Sapper
Tuppen, H. R.	Army Service Corps	Lieutenant
Walsh, B. P. K.	Cape Fortress Engineers (R.E.)	Sapper
Young, C.	Royal Flying Corps	Air Mechanic

THE JOURNAL OF
The Institution of Electrical Engineers

Vol. 53. 15 MARCH, 1915. No. 244.

ELECTRICITY APPLIED TO MINING.

By CHARLES P. SPARKS, Member.

[illegible]

[illegible]

INTRODUCTION.

In a previous paper [illegible] the author [illegible]

[illegible]

[illegible]

[illegible] COAL COMPANY.

In 1905 the author described the Aberdare section of [illegible]

[illegible]

* [illegible]

being $2\frac{1}{4}$ miles; and in the Rhymney Valley six collieries, the distance of the furthest pit from the power house at Penallta being 7 miles. The distance between the Middle Duffryn power house (Aberdare Valley) and Britannia Colliery (Rhymney Valley) is some 9 miles.

Following the electrification of a large part of the steam plant driving the older collieries, for some years all additional power requirements have been supplied electrically, but the principal developments have been the high-lift pumping plants and the equipment of the new Britannia Colliery at Pengam.

After considering alternative advantages of main steam

SYSTEM.

Aberdare Valley—3,000 volts 3-phase 50 periods, neutral earthed.

Rhymney Valley—10,000 volts 3-phase 50 periods, neutral earthed.

Transmission—Aberdare to Rhymney, 20,000 volts 3-phase 50 periods.

Individual drive—

Larger motors ...	3,000 volts	3-phase
Motors below 50 h.p.	500 ,,	,,
Lighting	110 ,,	single-phase

FIG. 1.—Transmission Lines, Aberdare Valley Collieries.

winding, the Powell Duffryn Company decided to drive the whole of the plant at the Britannia Colliery electrically.

The main winder house and the electrical equipment were erected before the sinking was started. The sinking was commenced in June 1910, and the two shafts, each 22 feet in diameter, were sunk to a depth of 750 yards by September 1913. This sinking was seriously impeded by the quantity of water met with, and for many months the continuous input for pumping alone averaged 1,000 kilowatts.

The 3-phase 50-period system which was adopted as the standard of the Company in 1903 has proved sufficiently flexible to be used for all colliery purposes, the working pressure being raised by static transformers as the distance of transmission and the power requirements increased. While no one system is completely satisfactory for every form of drive, in the opinion of the author the 3-phase 50-period system is more flexible than any other, and its use is considered under the following headings:—

Generators (*turbo-alternators*).—Speed 3,000 and 1,500

[illegible]

[illegible]

[illegible]

25 frequency.

[illegible] OF ENERGY.

[illegible] individual case must be considered on its merits. Speaking generally, when a supply is available from a power company it should pay individual collieries to purchase the electrical energy required and so avoid adding to the [illegible]

Where, however, the requirements of a single colliery [illegible] companies, it is advisable for such undertaking to generate its own electricity supply.

The use of exhaust-steam or mixed-pressure turbines has [illegible] cost of conversion to complete electrification is seldom [illegible] power house to be economically supplied electrically.

[illegible] profitably utilized for supplying electricity for additional [illegible]

[illegible] severity of labour troubles in recent years the [illegible] of installing generating plant for pumping and ventilating

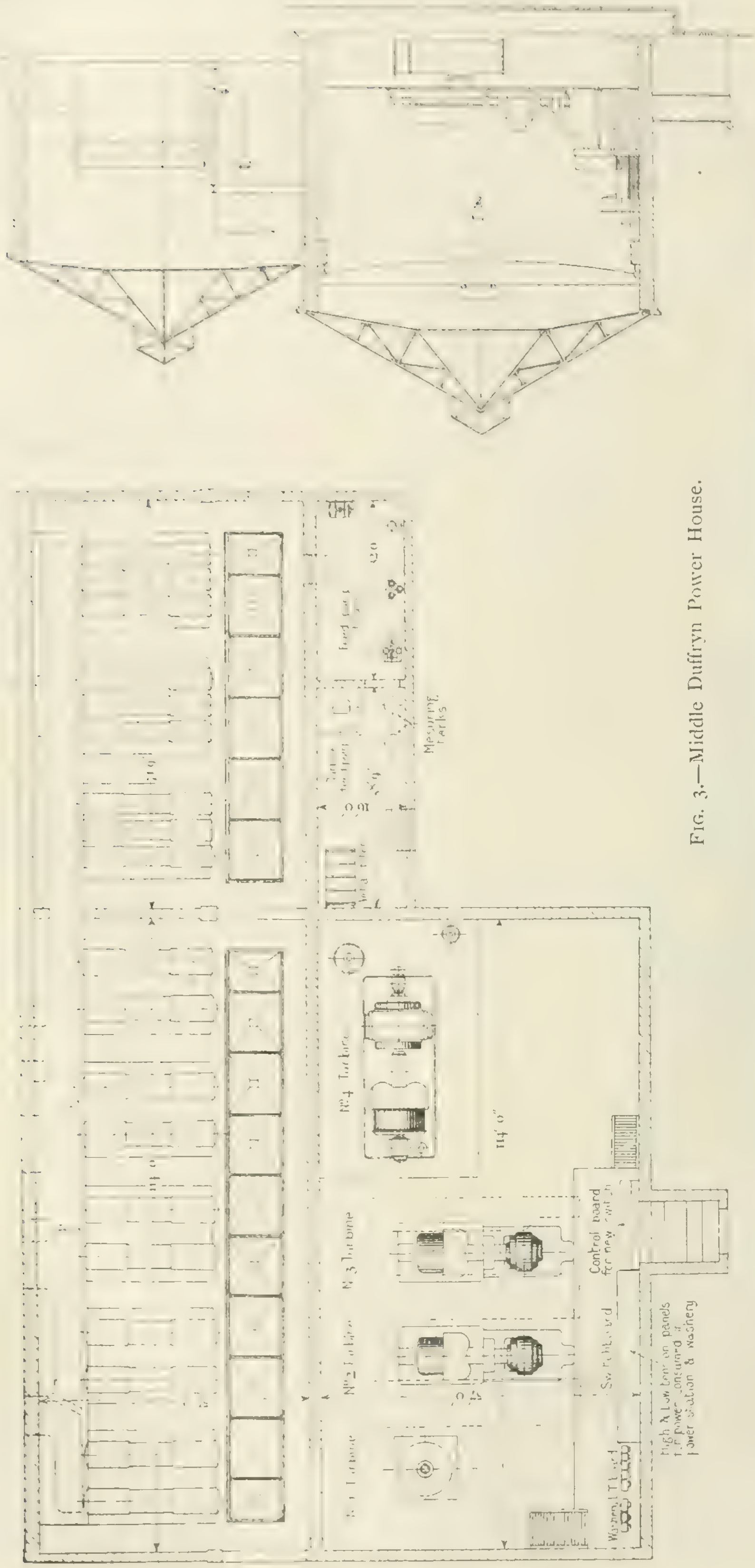


FIG. 3.—Middle Duffryn Power House.

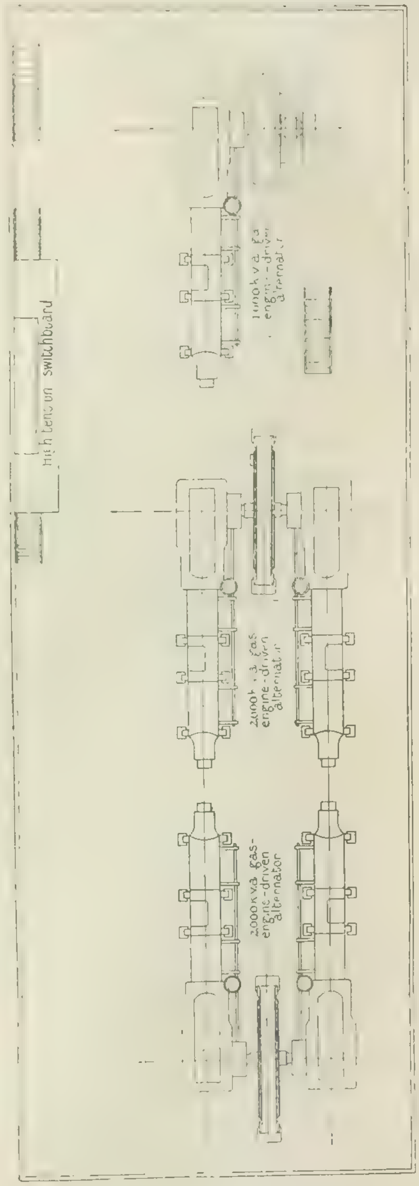


FIG. 4.—Bargoed Power House.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

turbo-alternators at 1,500 r.p.m.; the rating of this station being 6,000 kw.

Bargoed.—Two 1,600 kw. Nuremberg gas engines driving A.E.G. flywheel alternators at 100 r.p.m.; one [illegible] plant installed in this station totalling 6,000 kw.

[illegible] steam turbines driving Dick Kerr generators at 1,500 r.p.m.

The total generating capacity of all the stations is therefore 24,000 kw.

[illegible] Duffryn and Bargoed power stations.

[illegible] of a satisfactory supply of water offers considerable difficulty. [illegible]

[illegible] the workings, the pond has been supplemented by two [illegible]

[illegible] exciter armature mounted on an [illegible] shaft, the field [illegible]

[illegible] lation, [illegible] is effected by a fan [illegible]

[illegible] surface, is immediately under and parallel to the turbine. The turbine exhaust and the condenser are connected by a [illegible]

[illegible] slip-ring type) being fixed at the floor-level. The circu- [illegible] centrifugal pump through the air ejector.

[illegible] suction.

[illegible]

	[illegible]	
	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
Bargoed	[illegible]	[illegible]

Elliot.—The first exhaust-steam plant was erected at Elliot Pit, and consisted of two 500 kw. exhaust-steam Rateau turbines and Dick Kerr alternators, steam being delivered from the main winders to two Rateau accumulators.

The condensing plant comprises jet condensers with dry-air pumps, the circulating water being cooled by spray coolers.

This plant has been in use since 1909; and whilst satisfactory service is obtained during the normal winding hours, the use of this plant is limited to the day shift as it cannot be run efficiently on live steam.

Penallta.—The second application was at Penallta, where the exhaust steam from the two main winders and a compressor is utilized through two Rateau steam accumulators in conjunction with two 3,000 kw. Westinghouse mixed-pressure turbo-alternators.

The turbines are designed to give an output of 1,800 kilowatts with 60,000 lb. of low-pressure steam, and when working mixed pressure to give an output of 3,000 kilowatts with 60,000 lb. of low-pressure steam and running at 2,500 r.p.m. The auxiliary turbine, which develops 150 b.h.p., exhausts into the low-pressure steam system between the accumulator and the main turbine.

The following are the consumptions of low-pressure and high-pressure steam per kilowatt-hour when working under mixed-pressure conditions:—

Load	Lb. of Low-pressure Steam	Lb. of High-pressure Steam	Vacuum (Bar. = 30 in.)
Full	20	6·4	27·5
3/4	26·6	3·6	27·65
1/2	40	—	27·9

The plant has been in operation since 1912.

Bargoed.—The latest application is at Bargoed, where the exhaust from three main winders, steam compressor, and fan is utilized. Owing to the considerable back

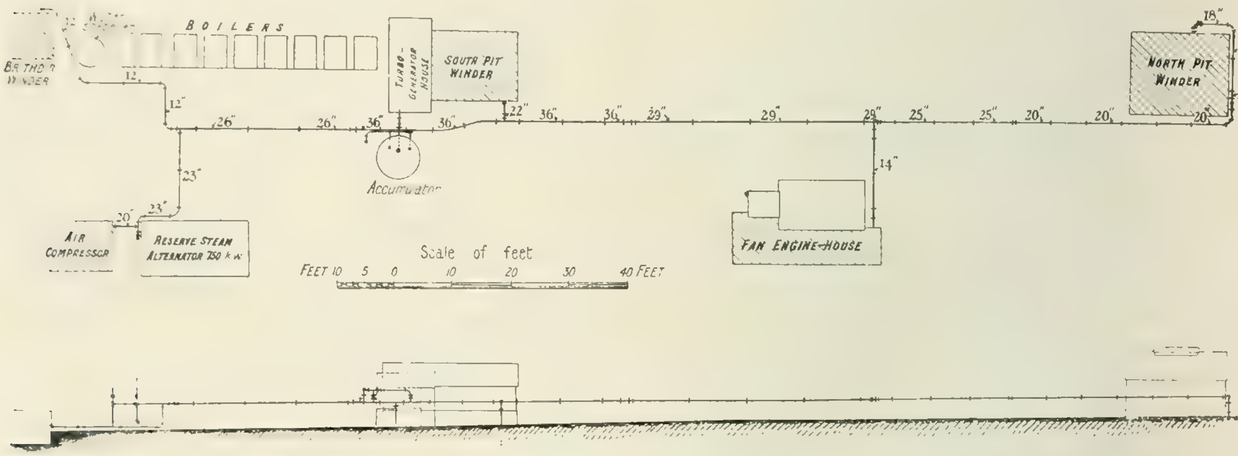


FIG. 5.—Bargoed Exhaust-steam Mains and Accumulator.

19,000 lb. of high-pressure steam at 150 lb. per sq. in., 100 degrees F. superheat.

As this plant works in parallel with the gas-engine station at Bargoed, close speed regulation was necessary, otherwise the gas-engine plant would have been overloaded each time the plant changed from high-pressure to low-pressure steam.

The makers were very successful in this application, tests showing that the alteration of frequency when changing from high-pressure to low-pressure steam did not exceed 0·3 of a period. The interchange of load when the gas-engine station is working at an average load of 1,800 kilowatts and the turbine load is 2,000 kilowatts does not exceed 500 kilowatts.

The condensing plant for each turbine is designed to deal with steam at the rate of 80,000 lb. per hour, the surface condensers having a cooling surface of 15,000 square feet.

The condenser auxiliaries consist of an auxiliary steam turbine driving a Leblanc air pump, a centrifugal cooling-water pump, and a condensed-steam extracting pump, and pressure on the main winders with the Rateau system (the back pressure varying from $2\frac{1}{2}$ to $3\frac{1}{2}$ lb.) it was decided to adopt the Samuelson system.

The steam accumulator is of the gasholder type having a capacity of 12,000 cubic feet, the dimensions being:—

Internal diameter	30 ft.
Height closed	19 „ 2 in.
Height extended	39 „ 6 „

The average quantity of steam dealt with is 75,000 lb. per hour, the momentary maximum rate of flow being 160,000 lb. per hour, any excess steam not used by the turbine passing to the feed-water heater.

From the working of this plant since October 1914 it has been found that the back pressure on the main winders never exceeds 0·5 lb.

Owing to the pressure variation being very small it is impossible in this instance to control the admission of the low-pressure steam to the turbine by change of pressure, as in the Rateau system; the supply of exhaust steam is therefore directly controlled from the steam accumulator,

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	—	28·5
[illegible]	—	[illegible]	28·7[illegible]

[illegible] fixed in the turbine house, but this is only operated in an [illegible]

The following table shows the progress made in reducing [illegible]

[illegible] heating the ovens, the [illegible]

	[illegible]
(1) [illegible]	[illegible]
(2) [illegible]	[illegible]
(3) Firing boilers	[illegible]

[illegible]	[illegible]
Hydrogen	[illegible]
Methane...	[illegible]
Carbon dioxide...	[illegible]
Heavy hydrocarbons	[illegible]
Oxygen	[illegible]
Carbon monoxide	[illegible]
Nitrogen...	[illegible]

Thermal [illegible]

[illegible] double-acting 4-cycle, are direct coupled to flywheel [illegible] rating, running at 3,000 volts and 100 r.p.m.

[illegible]

	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Penallta (1911) ...	2	4,000	1,500	[illegible]	[illegible]	[illegible]
[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible] (Bargoed)

[illegible]

Type—Regenerative "Koppers" and "Simplex"

Coal—average quantity carbonized per week 4,700 tons

[illegible]

[illegible] scheme for dealing with small coal. The "smalls" from the Rhymney Valley are washed and mixed at Bargoed; after extracting the nuts, beans, and peas, the smaller [illegible]

[illegible] per cylinder [illegible]

[illegible] found to be [illegible]

and exhaust valves, and since 1912 the plants have been worked at average loads of 600 and 1,200 kilowatts, the combined maximum load being 2,200 kilowatts. Since modifying the rating of this plant, the life of pistons, piston rods, and exhaust valves has increased, and no cylinders have been cracked.

Gas consumption.—Tests showed that the heat consumption of the 2,000 k.v.a. sets was :—

At full load	...	12,800 B.Th.U. per kw.-hour
At half load	...	20,400 „ „

Load factor.—In order to utilize the surplus gas to the best advantage, electric pumping was adopted simultaneously with the erection of the gas-engine plant, and by providing high-power pumps and increasing the size of lodge rooms it was found possible to confine the hours of pumping to from 8 to 12 per day at the Elliot Pit. The gas-engine plant thus supplies the general colliery demands during the day and the main pumping at night.

With an output of 14 million units per annum and a maximum load of 2,200 kilowatts, the annual load factor of the gas-engine station is 72 per cent.

(*d*) Fuel.

In the case of small collieries, refuse or low-grade fuel for which there is no ready sale is used with advantage, as fuels of this character are not worth transportation; but where the power demand is important, the extra cost and wear and tear of boiler plant, the cost of labour in stoking, and the difficulty of maintaining a regular supply of steam justify the use of higher-grade fuel of uniform quality.

Until recent years the South Wales coal-field has been at a great disadvantage owing to the unsuitability of the average class of "dry smalls" for use on mechanical stokers, the main product of the coal-field being of special value for hand-firing for marine and locomotive purposes.

With the increasing importance of small coal much attention has been given to mechanical stokers, and the modified form of furnace introduced by Messrs. Babcock & Wilcox, in conjunction with Mr. E. L. Hann, has solved the problem of burning "dry small" coals.

The tests, of which particulars are given in Appendix I, show the results obtained at the Penallta Colliery.

Fuel consumption.—No general statement can be given as to the total fuel consumption, as in the case of the Powell Duffryn Company 14 million units are generated by coke-oven gas, about 14·5 million by exhaust steam, and the balance of 21·5 million by live steam.

In the case of the Aberaman Collieries, the weekly coal consumption, operating on a station load factor of 47 per cent, is 2·9 lb. of fuel (one-third washed "duff" and two-thirds grains), the average calorific value as fired being 12,600 B.Th.U.

The comparative heat consumptions per watt-hour for the gas and steam stations are :—

	Annual Load Factor	Average No. of B.Th.U. per Watt-hour
Gas	72 %	18·0
Live steam	47 %	36·5

Transmission System.

(*a*) Distribution Above Ground.

Experience has proved the reliability of overhead transmission with bare conductors for colliery supply. Apart from the saving in first cost, the main risk through the use of cables is avoided, namely, subsidence.

To secure safety it is advisable to screen the overhead conductors at all points where they cross traffic. The efficiency of screening is dependent on reliable earthing, which is best secured by a continuous, stranded earth-wire of substantial section, the section having a definite ratio to the section of transmission lines protected, the earth-wire being effectually earthed at each end and connected to intermediate earth-plates every 300 or 400 yards. In order to minimize risk, all main conductors round the pit head should be run as armoured cable.

The overhead system used by the Powell Duffryn Company in the Aberaman Valley was described in the previous paper.* The following modifications have been made to meet the developments in the last 9 years :—

All collieries in the Aberdare Valley are now supplied by a system of 3,000-volt ring mains, protected on the Merz-Price system.

The section of the main feeders of hard-drawn copper has been increased to 0·15 sq. in. (19/12 S.W.G.), the wires being grouped in a triangle, for single circuits 3 ft. 6 in. vertically and 4 ft. 6 in. horizontally; with double circuits the conductors are carried on three cross-arms, the circuits being spaced 4 ft. horizontally and the phases 3 ft. vertically apart.

The pilot wires for the Merz-Price system consist of either one or two 3-core 7/21 S.W.G. paper-insulated lead-covered cables, suspended from galvanized steel catenary wire, 7/14 S.W.G., by raw-hide suspenders, these conductors being carried at the extremity of a fourth cross-arm fixed about 4 ft. below the main conductors.

The average length of span is 100 ft.

Wood poles.—Little depreciation is noticeable at the base of the creosoted wood poles, which have been erected over 10 years.

The overhead wires radiating from the Middle Duffryn power station have been displaced by 3-core paper-insulated lead-covered armoured cables to a point well clear of the power station, washery, and railways. The overhead wires branch from brick towers, in which the choking coils and horn-gap lightning arresters with liquid resistances are placed.

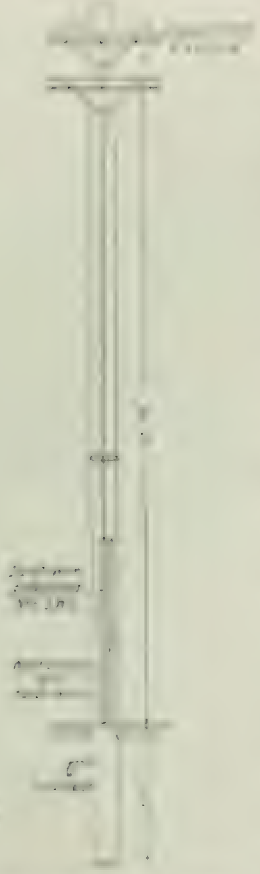
Rhymney Valley 10,000-*volt transmission lines.*—These run from Penallta to Bargoed a distance of 3½ miles. Duplicate circuits are run between Penallta and Pengam on the same "A" and "H" poles, and between Pengam and Bargoed on separate poles, the two pole lines being about 30 ft. apart. This allows the Britannia Colliery, which is completely electrified, to be supplied from either of two power houses by two sets of duplicate transmission lines, grouped on three independent pole lines.

Wood poles are employed 36 ft. long, the maximum diameter at the base being 11½ in. and at the top 7½ in., and the pole being buried in the ground 5 to 6 ft.

The conductors are hard drawn copper, 0·25 sq. in. section (37/13 S.W.G.). The phases are spaced vertically

* See page 389.

[illegible]



[illegible]

Each circuit is protected on the Merz-Price system. The [illegible] 4 ft. below the [illegible] earth connection [illegible]

The overhead transmission lines are connected to the [illegible] brick towers [illegible] earth.

[illegible]

[illegible] isolating switches.

[illegible] conductors.

[illegible] 3,000 and 10,000-volt systems.

[illegible] drawn copper wires arranged on normal spans with the phases 5 ft. apart vertically, the split phases being at 4 ft. horizontal centres.

[illegible]

consist at each end of not less than 300 yards of 0·1 sq. in. split-phase paper-insulated lead-covered double-wire-armoured cable, the armouring being connected to the continuous earth-wire at each end and to the main earth connections at the Middle Duffryn power station and Britannia Collieries.

Figs. 1 and 2 show the general network of the Aberdare and Rhymney Valleys, and Fig. 9 the route of the 20,000-volt transmission line. With the completion of the latter the Britannia Colliery will be fed from three power houses by three independent routes. The annual load factor of the entire undertaking will be as high as 55 to 60 per cent, while the reserve plant in either valley will be available for the whole undertaking.

(*b*) Distribution Underground.

In contrast with some other countries the working conditions in the British coal fields require all conductors to be insulated, and in order to prevent damage due to movement in the workings all conductors are usually suspended by leather thongs.

To ensure continuity of supply for important pumping plant duplicate double-wire-armoured cables are used, either placed on opposite sides of the shaft or preferably run in separate shafts so as to prevent the supply being interrupted by mechanical injury.

When electricity was first applied to mining on a large scale two distinct cable systems were used. In one system the aim was to obtain safety by insulating and separating the conductors, and in the other by the use of multicore armoured cable. The latter system has been used by the Powell Duffryn Company since 1903 with the cable sheaths earthed.

The Special Rules issued in 1905 under the Coal Mines Regulation Act, 1887, permitted the use of both systems. Following the Report of the Departmental Committee, consisting of Mr. (now Sir) R. A. S. Redmayne, Mr. C. H. Merz, and Mr. R. Nelson, in 1910, the new Rules issued under the Coal Mines Act, 1911, finally decided this question, Regulation 129 calling for cables with a metallic covering, electrically continuous, and efficiently earthed where the voltage exceeds low pressure (250 volts).

(*c*) Earthing Connections.

Regulation 125 (*b*)* under the Coal Mines Act, 1911, states :—

"All the conductors of an earthing system shall have a conductivity at all parts and at all joints at least equal to 50 per cent of that of the largest conductor used solely to supply the apparatus a part of which it is desired to earth. Provided that no conductor of an earthing system shall have a cross-sectional area of less than 0·022 of a square inch."

To improve existing systems a separate earth cable is permissible, but to prevent the earth connection being opened it is advisable in order to give the necessary conductivity, where the section of the armouring is insufficient, that the earth conductor should form an integral part of the cable :—

(1) by using the copper sheath under the lead,
(2) as an additional conductor (*i.e.* a 4-core cable for 3-phase working),

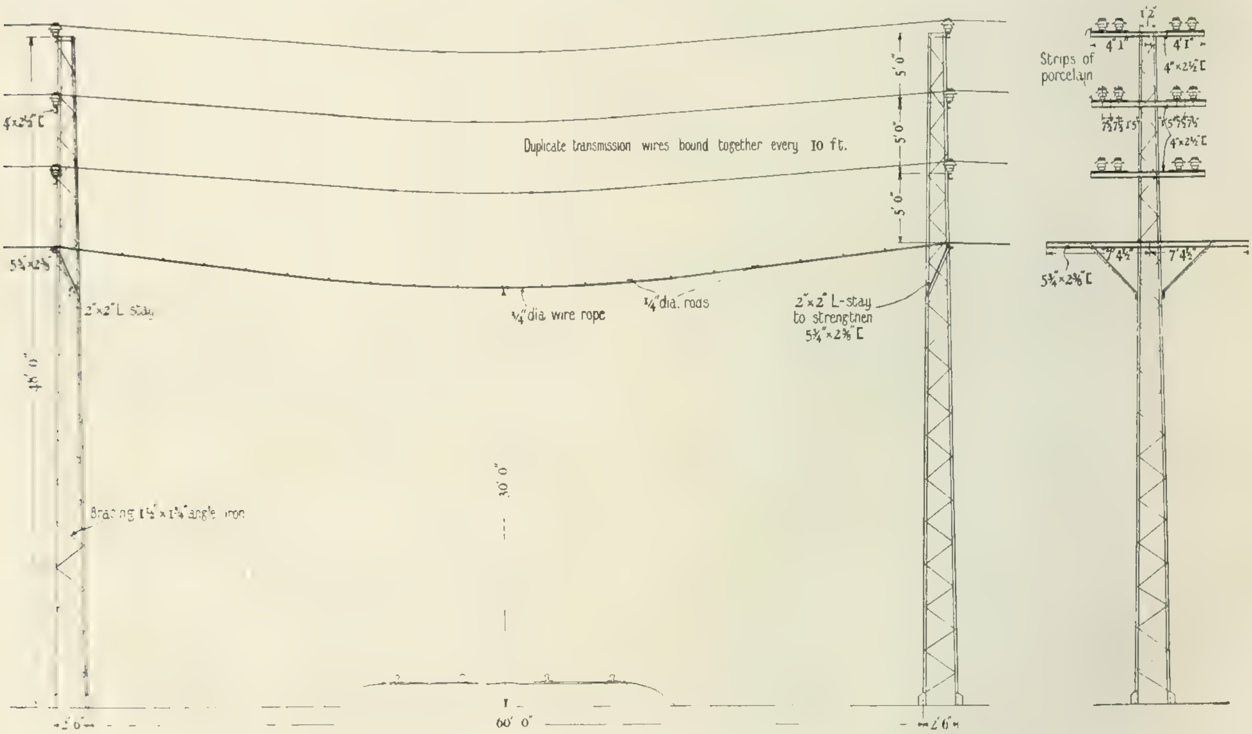


Fig. 8.—Railway Crossing of 20,000-volt Line.

* General Regulations dated 10 July, 1913, made by the Secretary of State under Section 86 of the Coal Mines Act, 1911 (1 & 2 Geo. V, c. 50).

[illegible]

[illegible]

danger."

[illegible]

[illegible]

an earthing system at the surface of the mine."

[illegible]

necessary to add a number of earth-plates connected to [illegible]

as regards moisture. As so much depends upon the earth connections being in order, and as earth-plates are necessarily out of sight, it is advisable always to provide for the main connection to earth at the surface of the mine at least two plates placed at some distance apart, but connected together in case of the failure or disconnection of one of them.* Two earth-plates properly placed 20 or 30 ft. apart in good surroundings and connected to each other are nearly twice as efficient as a single earth-plate equal in surface area to the two together.

contact surface forms a good earth connection. Earth-plates should be not less than 4 ft. square, placed preferably in an upright position in the ground, packed hard on each side with about 12 in. of broken coke free from sulphur. The depth at which they are buried must depend upon the condition of the ground in regard to moisture. The place selected should be permanently wet or at least damp."

Whilst recognizing the difficulty of specifying how an efficient earth connection should be made, the author is in agreement that the main "earth" must be placed at the

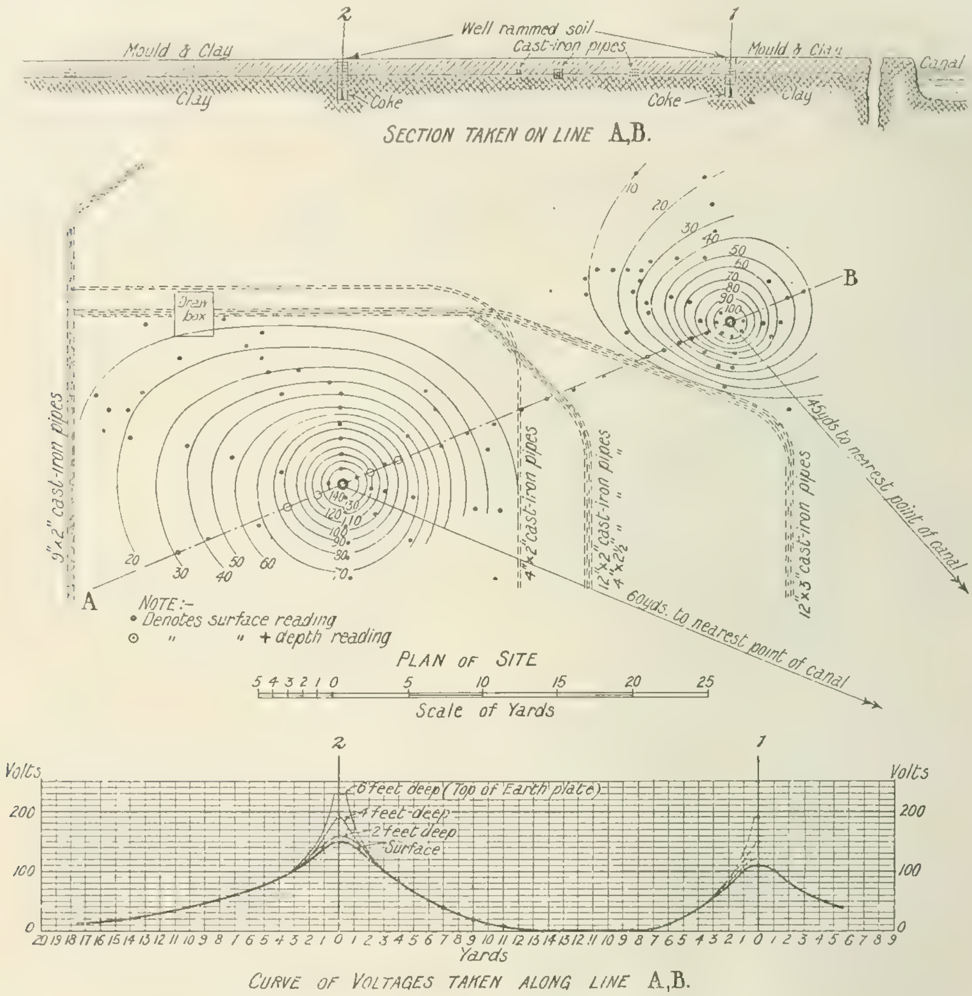


FIG. 10.—Location of Earth-plates Nos. (1) and (2), and Potential Gradient in vicinity of Earth-plates when passing 100 amperes at 50 periods.

"Earth-plates may be of copper, cast iron, or galvanized iron.

"A cast-iron plate with projecting forks to give a large

surface of a colliery, owing to the difficulty of constructing and maintaining efficient earth-plates underground.

With regard to the type of "earth" at the surface, it is desirable, instead of eaving this point to be settled individually, that the usual power-station practice should be followed in which several earth connections are made by a copper ring-main connected to steam condensers, circulating-water pipes, feed pipes, and other metal-work in direct connection with earth, or, in cases where it is not possible to make such an earth connection, that the contact area of each coke bed should be materially greater than that specified in the General Regulations issued under the

* In the Regulations made by the Board of Trade under the provisions of Special Tramways' Acts or Light Railway Orders for the earthing of rails forming return conductors, it is provided that two earth-plates (or connections) not less than 20 yards apart shall be used, and further that the following test shall periodically be applied (Regulation 5 (b)):—

"The earth connections referred to in this regulation shall be constructed, laid, and maintained so as to secure electrical contact with the general mass of earth, and so that, if possible, an electromotive force, not exceeding four volts, shall suffice to produce a current of at least two amperes from one earth connection to the other through the earth, and a test shall be made once in every month to ascertain whether this requirement is complied with."

[illegible]

[illegible] of broken gas coke, well rammed.

[illegible] the surrounding strata is about 40 square feet, which results in the resistance between the earth-plate and the outer coke surface being approximately 0·5 per cent of the total resistance to earth, with the coke bed surrounded by clay.

[illegible] excavations 4 ft. × 2 ft. × 8 ft. deep, the plates being surrounded by moist clay, which was reached 3 feet from [illegible] mould well consolidated. Plate No. (1) was 45 yards, and [illegible] 2 feet below the normal ground-level.

[illegible] by means of an electrostatic voltmeter, between an insulated exploring bar below the surface (and a weighted metal disc of 10 in. diameter for surface readings) and an [illegible]

[illegible] surface of the ground immediately above the earth-plate [illegible] appreciable difference of pressure between the surface and an exploring point 6 feet below.

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

To test the ability of these earth-plates to carry current for a considerable period, alternating current at 50 periods [illegible]

[illegible]	[illegible]	[illegible]
0	[illegible]	[illegible]
5	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

[illegible] coke bed owing to the temperature rising [illegible]

been not less than 500 volts above earth. Any such pressure on the earth-plates, although of momentary duration, is dangerous, as it would result in the cable

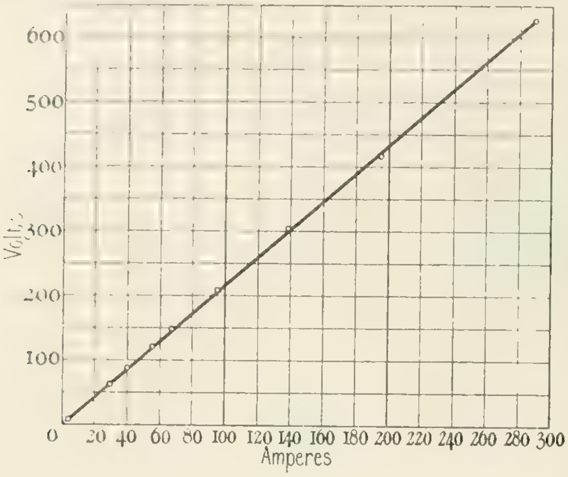


FIG. 11.—Pressure between No. (2) Earth-plate and Earth when Alternating Current at 50 cycles is passing.
Readings taken one minute after pressure applied.

sheathings and any metal connected to the main "earth" being raised to a dangerous pressure. It is therefore

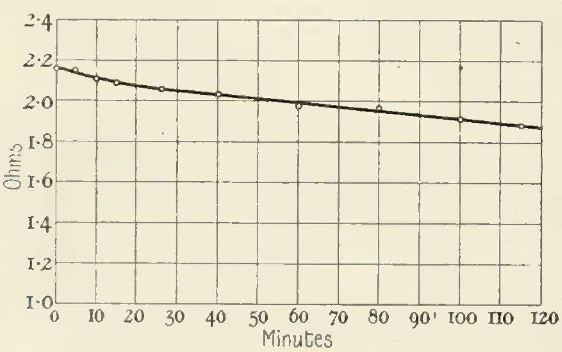


FIG. 12.—Fall in Resistance of No. (2) Earth-plate to Earth when passing Alternating Current a 50 cycles 600 volts for 2 hours.

essential that a different type of main "earth" should be used from that recommended by the Regulations, or else that the number of earth-plates be increased.

(c) EARTHING OF SYSTEM.

The general safety has been much increased by the Regulations issued in 1913, which provided that all conductors where pressure exceeds low pressure (250 volts) must be protected by a metallic covering electrically continuous and efficiently earthed; but the author suggests that when the Regulations are next under revision Regulation (124) should be amended so as to make it compulsory to earth the neutral point of all polyphase systems.

The main advantage of working with one point definitely earthed is the impossibility of continuing working with a definite fault on the system. While working with a fault on the system is disallowed by Regulation (124), the possibility of continuing working with one fault on the system is still considered an advantage by some of the advocates of an unearthed system.

Regulation 124 (c) states that—

"Every part of a system shall be kept efficiently insulated from earth, except that (1) the neutral point of a polyphase system may be earthed at one point only; (2) the mid-voltage point of any system, other than a concentric system, may be earthed at one point only; and (3) the outer conductor of a concentric system shall be earthed. Where any point of a system is earthed it shall be earthed by connection to an earthing system at the surface of the mine."

Under the General Regulations, Part 3 of Memorandum on Electricity Regulations, Regulation 124:—

"Section (c).— . . . In a modern 3-phase installation in which the apparatus and cables are carefully constructed and installed, it will usually be found desirable to earth the neutral point. In general it may be said the advantage of earthing the neutral point is increased by the use of cables provided with an efficient metallic covering."

"Section (d).—The most efficient means of indicating any defect in the insulation of a system is to arrange so that in the event of any leakage of current the faulty circuit shall be made dead automatically. This can be done immediately there is a fault to earth, provided one point of the system is connected to earth. . . ."

SWITCHGEAR.

(a) POWER STATIONS AND SUB-STATIONS.

The switchgear conforms to the standard practice in power stations.

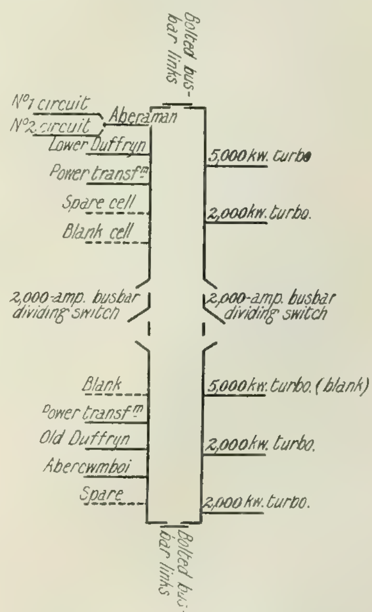


FIG. 13.—Diagram of Middle Duffryn Switchgear.

Middle Duffryn power station.—Fig. 13 shows the method of grouping the busbars, generators, and feeder switches.

The switchgear, which is erected in a separate building,

[illegible]

The generators are grouped as follows:—

[illegible]

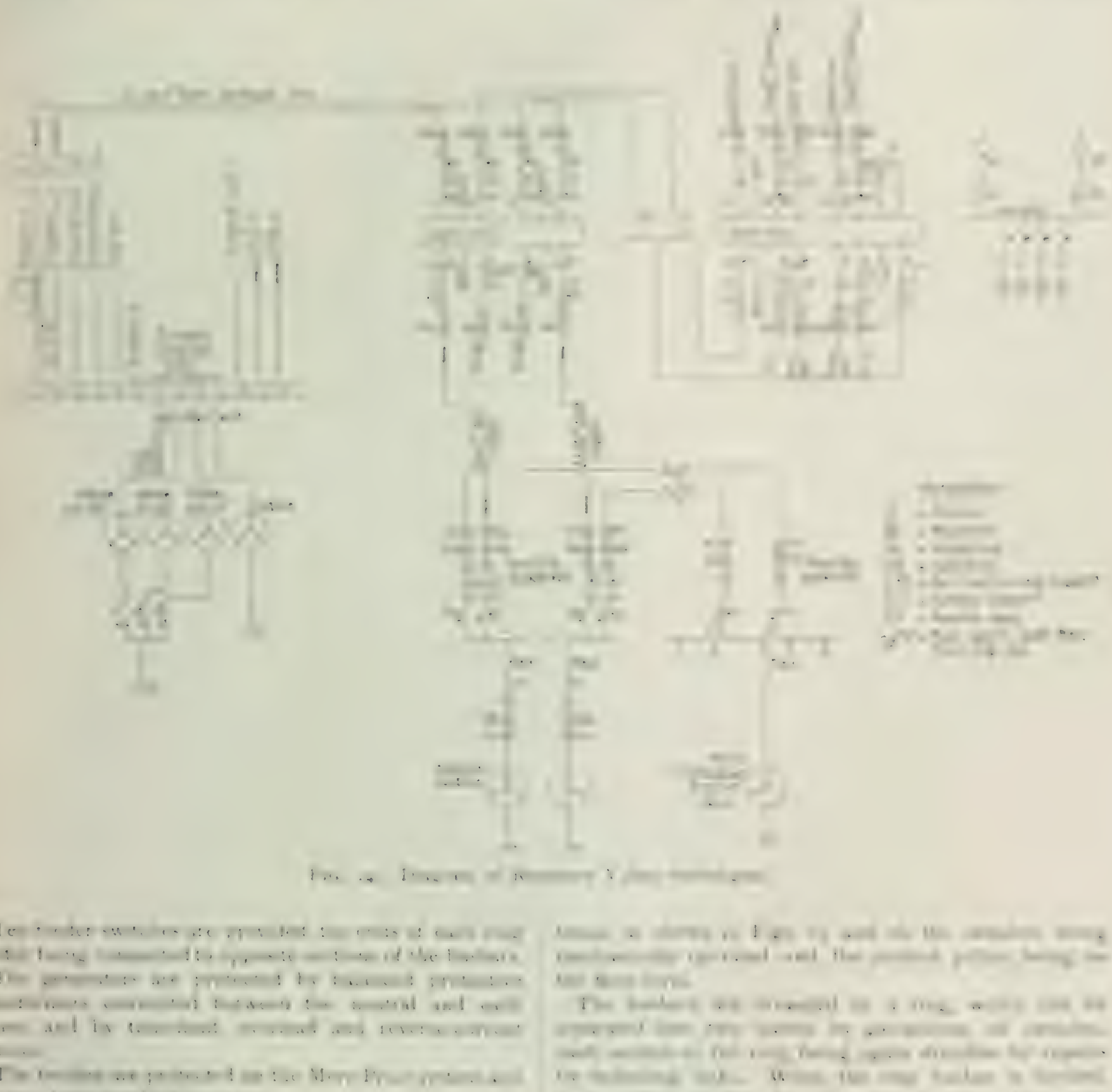


FIG. 14.—Diagram of [illegible] switchgear.

[illegible]

The 3,000-volt busbars are treated in a similar manner. In the first instance the supply was given to each section of the busbars by one 1,000 k.v.a. transformer. This equipment is now being increased to two 1,000 k.v.a. transformers per section.

Bargoed.—Fig. 14 shows the arrangement of the busbars, generators, and feeder switches. The busbars are in duplicate, the generators and feeders being connected to either of the busbars through interlocked isolating switches.

The busbars are in screened chambers, erected on the main engine-room floor-level, the switchgear and operating platform being 9 feet 6 inches above the main floor-level, as shown in Figs. 17 and 18.

The protective arrangements are as follows :—

Generators—Time-limit overload and reverse-current relays.

Feeders—Time-limit overload and Merz-Price protective system.

The pressure is controlled at the power station by Tirrill regulators. This has resulted in an improved power factor on very fluctuating loads. Having regard to the variation of 25 per cent in load in either valley in a few seconds, it was found difficult to maintain a satisfactory pressure until the plant at the various power houses was controlled by these regulators.

The power factor varies between the following limits :—

Aberdare Valley	0·7 to 0·85
Rhymney Valley	0·7 ,, 0·8

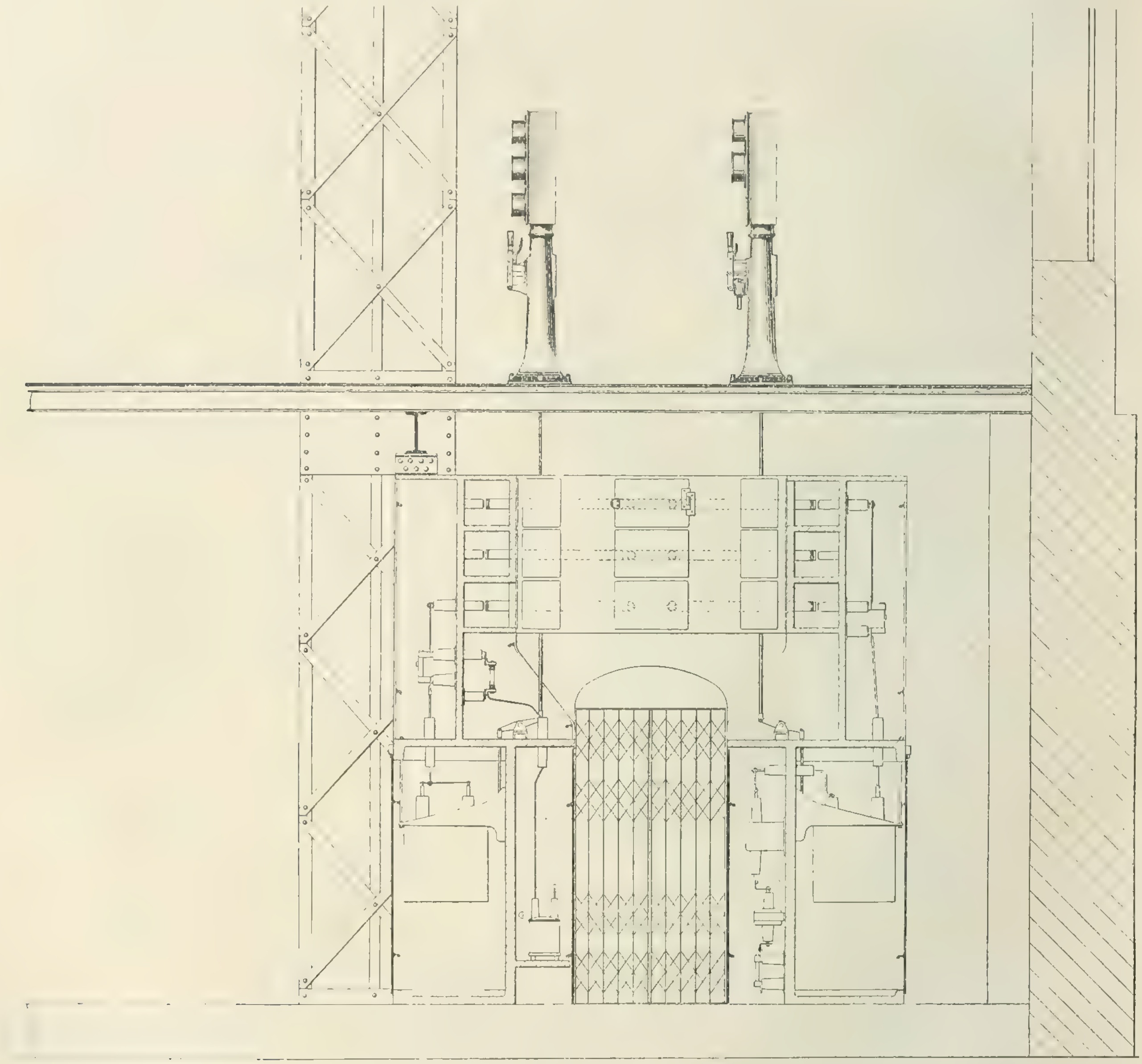
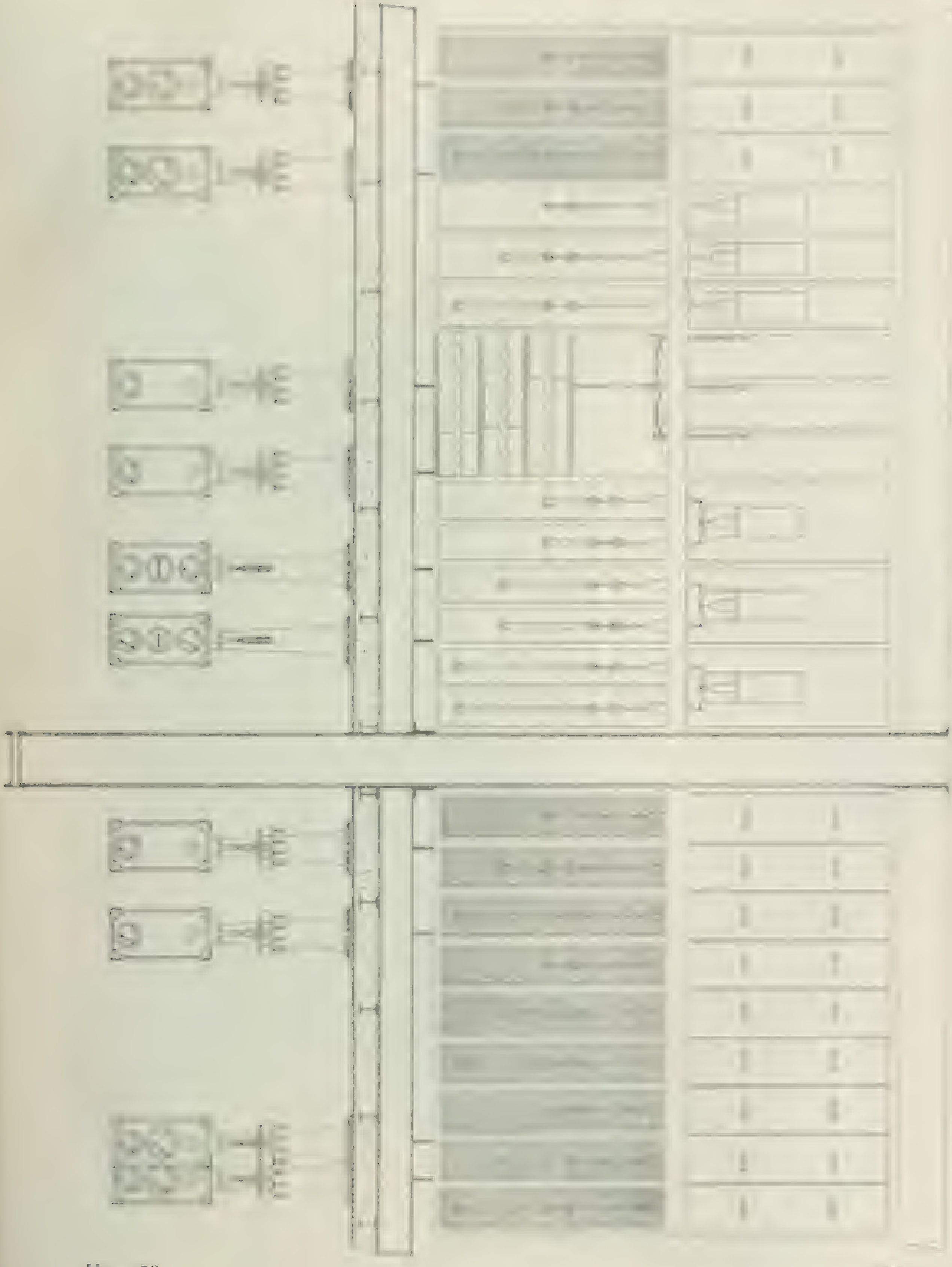


FIG. 15.—10,000-volt Switchgear, Penallta and Britannia Collieries.



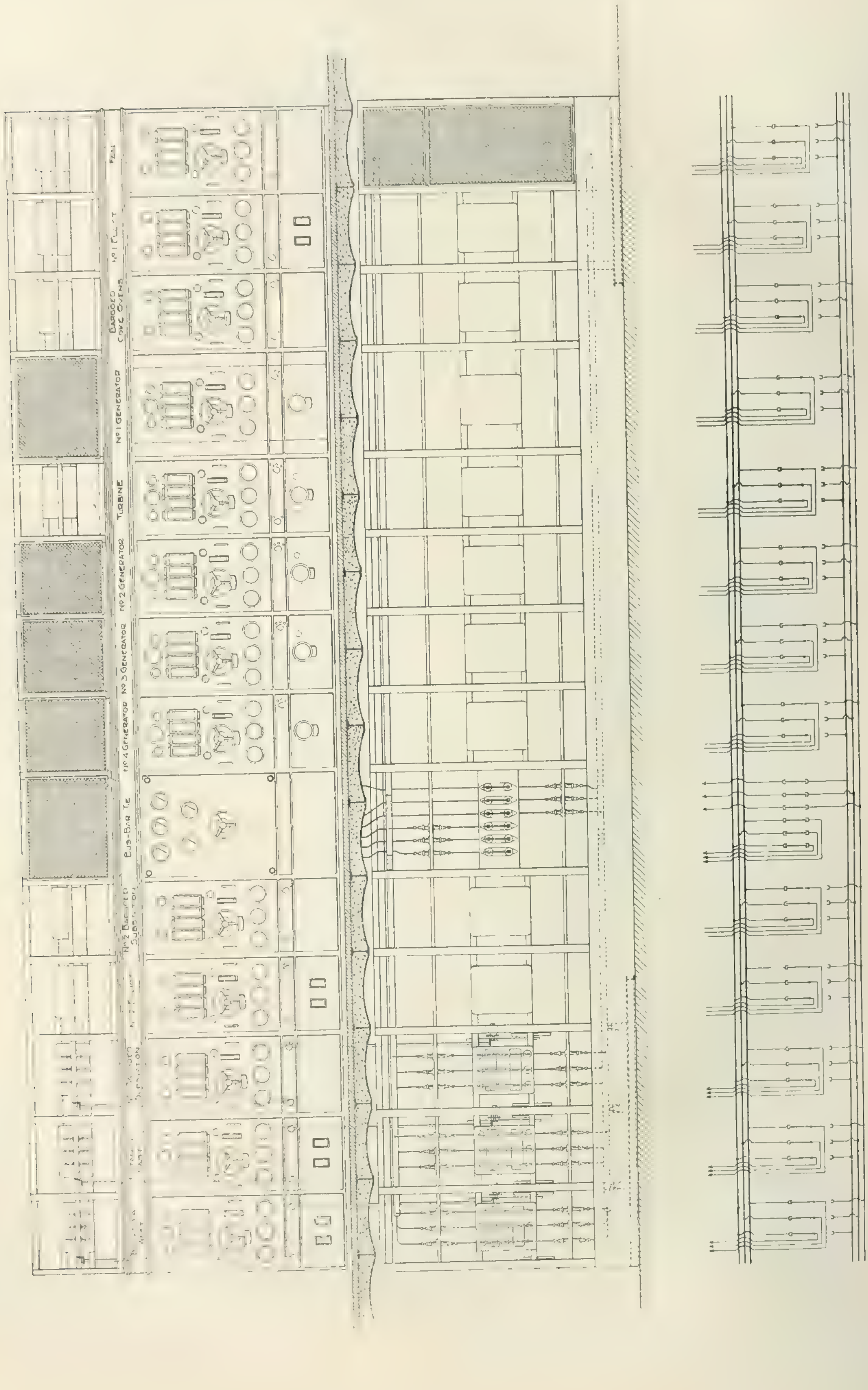


FIG. 17.—Bargoed Switchgear.

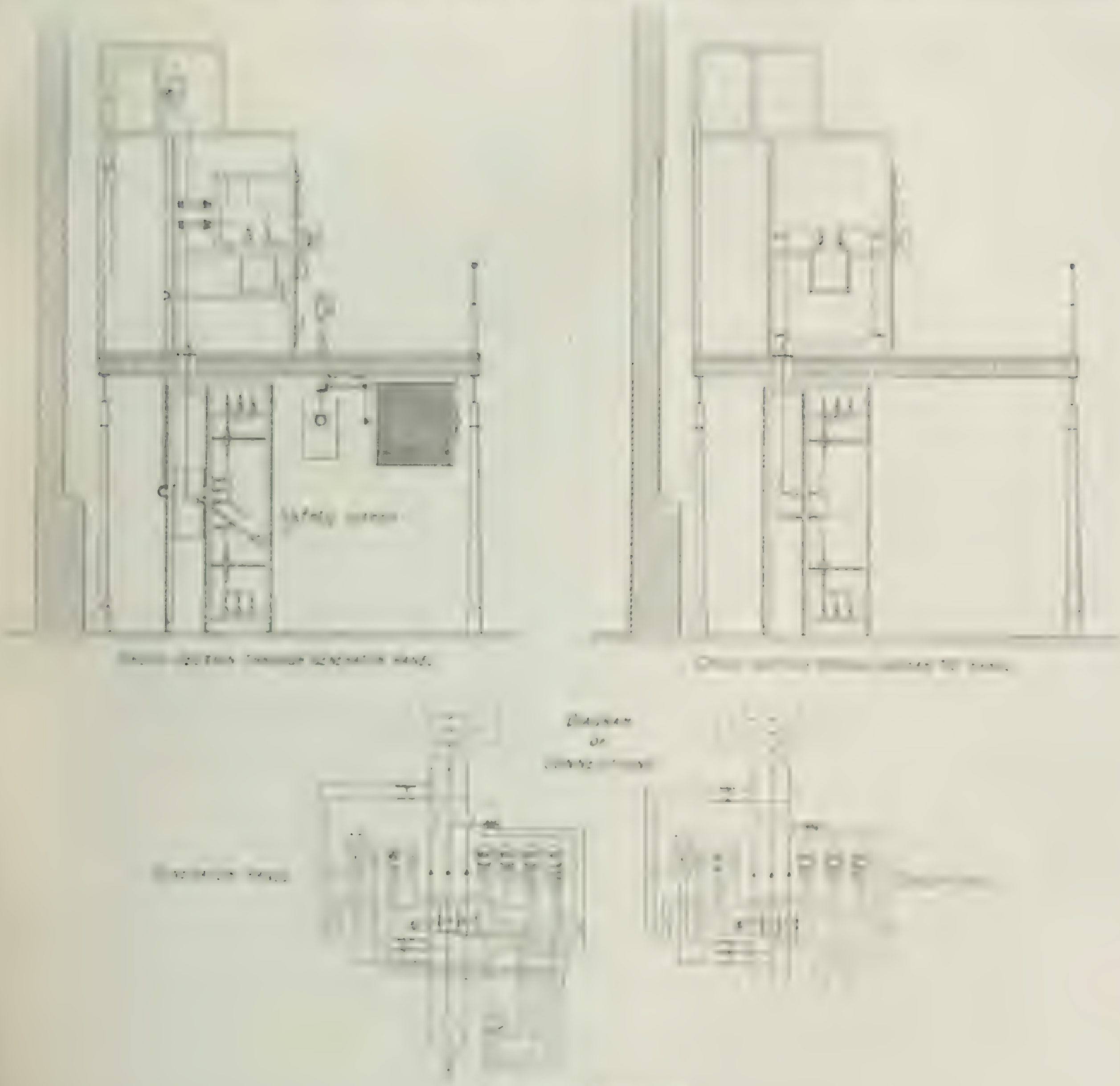


FIG. 18.—Ironclad Switchgear.

(b) MOTORS.

replaced with unprotected metal.

run at 3,000 volts, and their neutrals are earthed through resistances.

The first 10,000-volt sub-station equipment, which is now being increased, consisted of :—

Penallta.—Two mesh to star transformers 10,000/3,000 volts, rating 1,000 k.v.a., the transformers being of the oil-insulated, water-cooled type.
Britannia.—Three ditto.
Bargoed.—Two ditto.

For earthing the neutral point of the 10,000-volt side of the mesh-connected transformers at Bargoed, when the supply is maintained from Bargoed alone, neutral-point transformers are used.

	Main Winder with 12 ft. to 22 ft. Cylindro-conical Drum and Two Motors
Depth of shaft	730 yards
Output of coal per hour	360 tons
Net load of coal per wind... ...	6 ,,
No. of trams per cage	4
Diameter of rope	$2\frac{1}{8}$ in.
Max. speed of rope	72 ft. per sec.
Weight of unbalanced load ...	13 tons 2 cwt.
Time of wind	48 sec.
Time of each complete cycle ...	60 ,,

Converter sets.—The energy is converted by two converter sets, each capable of supplying one main winder (Fig. 19), each set consisting of an induction motor, two

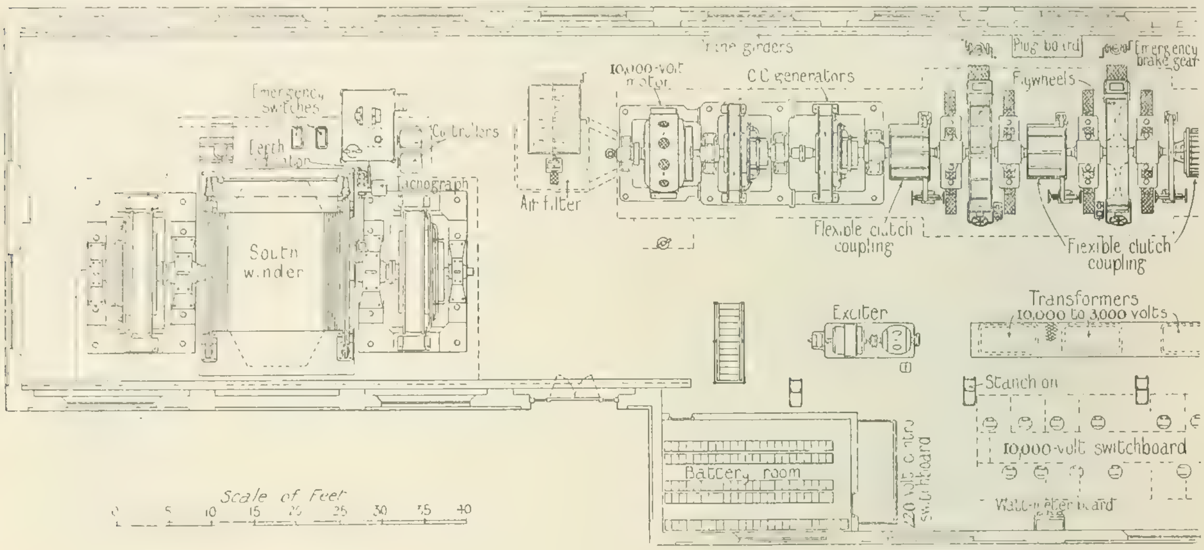


FIG. 19.—Arrangement of Electric

500-volt system.—Each colliery has duplicate 3,000/500-volt oil-insulated mesh-star transformers for supplying the smaller motors.

110-volt single-phase system for lighting.—This is supplied by small transformers connected across one of the phases.

Individual Drives.

(*a*) Main Winding—C.C. Motors.

The Britannia pits of the Powell Duffryn Company are equipped with two main winders, supplied by Messrs. Siemens Brothers Dynamo Works, the mechanical parts being by Messrs. Fraser & Chalmers.

The 10,000-volt 3-phase supply is converted to continuous current by two Ilgner converter sets.

The main winders each have a parallel drum 14 feet in diameter, for use during the sinking period, designed to form part of the final drum 14 ft. to 22 ft. cylindro-conical type. Each main winder is coupled direct to two motors, rated to develop as a maximum 4,300 horse-power.

The Ilgner sets are designed for a winder duty as under :—

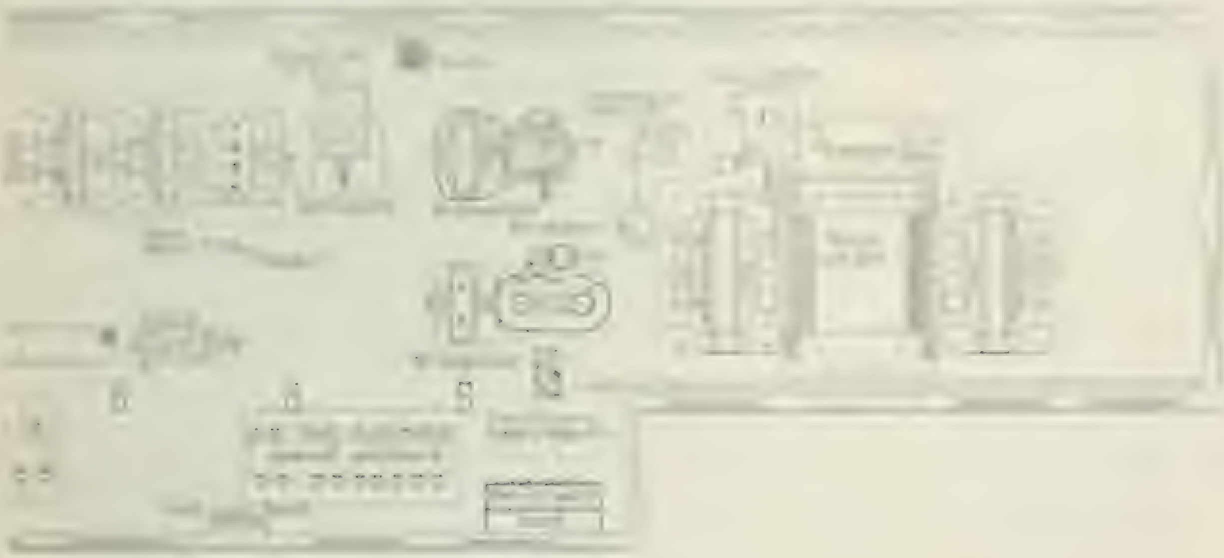
continuous-current generators, and a 30-ton flywheel. When the colliery is further developed a third (spare) Ilgner set will be added.

The two sets are erected in line, with three needle-type flexible couplings, combined with friction clutches between the wheels and converter sets, so that the two flywheels can be run together with either converter set, the two sets being of 100 ft. length over all.

Owing to the proximity of the winder house to the shafts, special care was taken in the design of the foundation. The main foundation consists of a reinforced concrete girder as shown in Fig. 20.

Ilgner converter sets. Induction motors.—During the sinking period one converter set was used for both winders, each of its generators supplying one motor on each winder. As the 10,000-volt supply was not available at the commencement of the sinking, the induction motors were supplied at 3,000 volts, their stator circuits being temporarily connected in mesh, the motors then each developing a maximum of 750 b.h.p., the motors being designed for full-load output, when star connected, at 10,000 volts.

The motors are of the enclosed self-ventilating type



Winding Plant at Britannia Colliery.

Stored energy at max. speed ...	31,000 ft.-tons

40 degrees C.

(C) The emergency brake.

winding motor while the brake is "full on," and also the brake cannot be applied whilst the full current is flowing in the motor.

An interlock is also provided so as to prevent the trip gear of the emergency brake being reset unless the main control lever is in the "off" position and the brake control lever in the "full on" position.

(A) The main control lever, which is connected to the main controllers and depth indicator, is controlled by cams on the latter so that the winding motor cannot be accelerated beyond a predetermined rate. Should the driver neglect to operate the control lever, the winding motor is automatically retarded and brought to rest.

to the motor shafts, the couplings being fitted with cross keys to relieve the bolts of the shearing stresses.

Brakes.—The drum is fitted with two sets of post brakes, the brakes being capable of pulling up and holding at any point in the shaft a lowering load of 8 tons.

In addition to a hand-operated band brake each flywheel is provided with an electromagnetic brake acting on the rim of the wheel and capable of bringing the converter set —with one flywheel—to rest from full speed in 8 minutes. The time taken by the same set to come to rest when running free is about one hour.

Operation.—During the sinking period each winder was operated by one motor, the drums being of 14 ft. diameter.

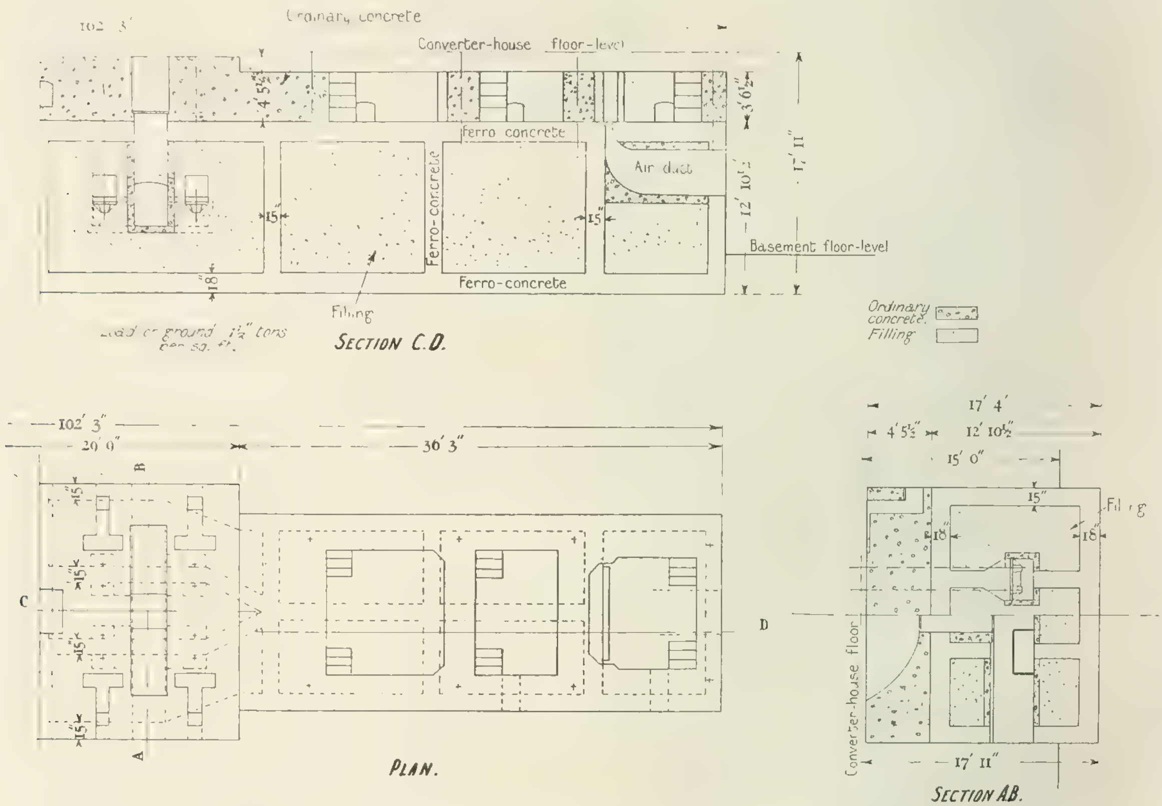


FIG. 20.—Half Foundation Block for Ilgner Converter Sets.

(B) The brake control lever is connected to a cross shaft which is coupled to the operating valve on the brake engine.

(C) The emergency brake is applied by either of the following means:—

(1) By hand.
(2) By the current failing.
(3) By the air pressure failing.
(4) In the event of overwind by either cage.
(5) In the event of excessive overload on the winding motor.

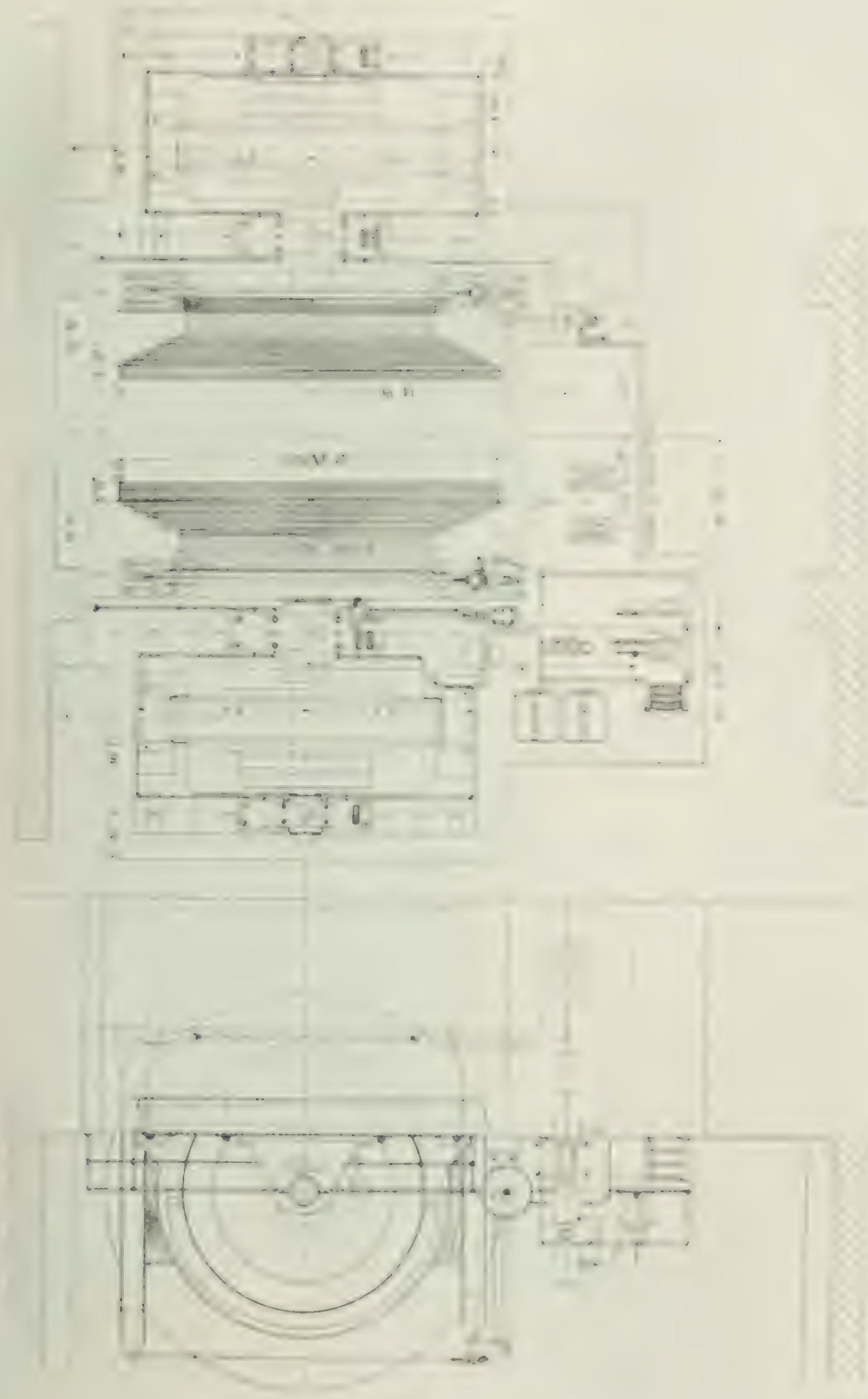
Mechanical parts.—The drum shaft is of 24 in. diameter and 3 in. bore, with journals 22 in. × 40 in. The shaft is forged with solid half couplings at each end for coupling

The loads consisted of men, rubbish, building material, and water, the maximum unbalanced load being 8 tons.

On completion of the sinking to 750 yards, operation was continued with the 14 ft. parallel drum with one motor raising two trams of coal or rubbish.

Following the partial opening-out of the colliery, as the cylindro-conical drum could not be erected for some months, a balance rope has been fitted on the winder with the 14 ft. drum, thus enabling one motor to raise four trams of coal (6 tons). Working under these conditions with 19 winds per hour and a winding time of 80 seconds, the number of kilowatt-hours taken by the Ilgner set averaged over one hour is 3·7 per ton of coal wound.

On completion of the cylindro-conical drum, when winding 360 tons of coal per hour, the input into the



Ilgner set will be 1,360 units per hour, or $3\frac{1}{4}$ units per ton of coal wound from 730 yards.

Main Winding—A.C. Motor.

A winder driven by a direct-coupled induction motor is erected at the Abercwmboi Colliery. The duty for which it was designed when fitted with a tail rope of equal weight to the winding rope is as follows:—

Depth of shaft	240 yards
Output of coal per hour	180 tons
Net load of coal per wind	50 cwt.
Number of trams per wind	2
Time of wind	35 sec.
Time of each complete cycle	45 „

The 3-phase motor is wound for 3,000 volts working pressure and has its rotor mounted on a continuation of the drum shaft. The continuous rating of the motor is 375 b.h.p., the maximum horse-power developed during the acceleration period being 700, with a power factor of 0·75.

A liquid controller is provided for starting and regulating the motor and is interlocked electrically with the oil-break main and change-over switches for reversing the motor. The resistance in the rotor circuit is determined by the height of the liquid, which is varied by a sluice valve connected to the controller. The liquid is cooled by pipes in which water is circulated, and is pumped from a storage tank in the base of the controller by a small electrically-driven centrifugal pump.

The winder is controlled by one lever which is connected to the main stator switch, the controller, and the brake engine.

The controller can maintain a minimum motor speed of 2·5 r.p.m. with one-tenth normal torque for 15 minutes for rope examination, etc.

The drum brakes are of the post type, and are weight-loaded air-operated with the Whitmore patent self-adjusting and variable-load appliances by which the driver can apply any desired load upon the brake according to the amount that the foot lever is pressed down.

The air supply for the brake cylinder is provided by an electrically-driven compressor set. This set consists of a compressor direct-coupled to a 3-phase motor with automatic starting and stopping, controlled by the pressure in the receiver, the working value of which is 60 lb. per square inch.

Should the power supply fail either through failure of the main supply or the operation of the overload main-switch relays, the brakes are automatically applied and the winder drum brought to rest.

A dial depth-indicator is used, with which is incorporated the overwinding gear. The latter in case of an overwind applies the brakes and cuts off current from the winding motor.

This winder has been in satisfactory operation for the last six years. The "peak" due to the sudden application of a load of 750 k.v.a. every 45 or 50 seconds is satisfactorily dealt with at the power station by the Tirrill regulator.

The number of units per ton of coal, wound without a balance rope, is 1·6 when winding 25 cwt. of coal.

(c) Pumping.

When steam was used for the main pumping the principal pumping stations for the Aberdare and Rhymney Valleys were at Middle Duffryn, Elliot Pit, and Bargoed.

At the former, two pumps each capable of delivering 80,000 gallons per hour were erected, the engines being on the surface and driving the pumps through reciprocating beams.

At Elliot Pit the equipment consisted of a triple-expansion engine and a Reidler pumping engine for 80,000 gallons per hour, erected underground in a large chamber near the pit bottom, steam being brought from the surface through a steam main about 1,600 ft. long.

A beam pump with engine at the surface was used at Bargoed.

The above plant has now been supplemented or displaced by single-lift centrifugal pumps, and in place of pumping continuously the main pumping is now confined at the Elliot Pit to 8–12 hours out of the 24 by enlarging the lodge rooms, the pumping in the other valleys being confined where possible to the night shift. This has a marked effect on the load factor of the power houses, and in the Rhymney Valley it has provided the continuous load necessary for the economical use of gas-engine plant.

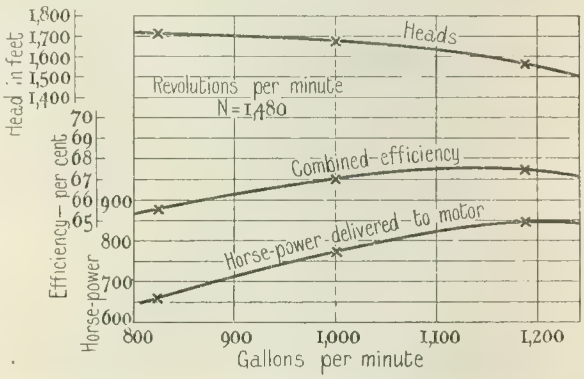


Fig. 22.—Curves of Test Results, 800 b.h.p. Centrifugal Pumps, Bargoed.

The quantity of water now pumped has largely increased and is now dealt with by the following main pumping plant.

Aberdare Valley.—(Abercwmboi) Three pumps each driven by a 600 b.h.p. 3-phase motor.

Head	1,015 ft.
Capacity	70,000 gallons per hour
Speed and type of pump	Sulzer 5-stage, 1,480 r.p.m.

(Aberaman) Two pumps each driven by a 350 b.h.p. 3-phase motor.

Head	722 ft.
Capacity	60,000 gallons per hour
Speed and type of pump	Sulzer 5-stage, 1,480 r.p.m.

(Ysybörwen) One pump driven by a 120 b.h.p. 3-phase motor.

Head	200 ft.
Capacity	40,000 gallons per hour
Speed and type of pump	Willans and Robinson 3-stage, 1,440 r.p.m.

[illegible]

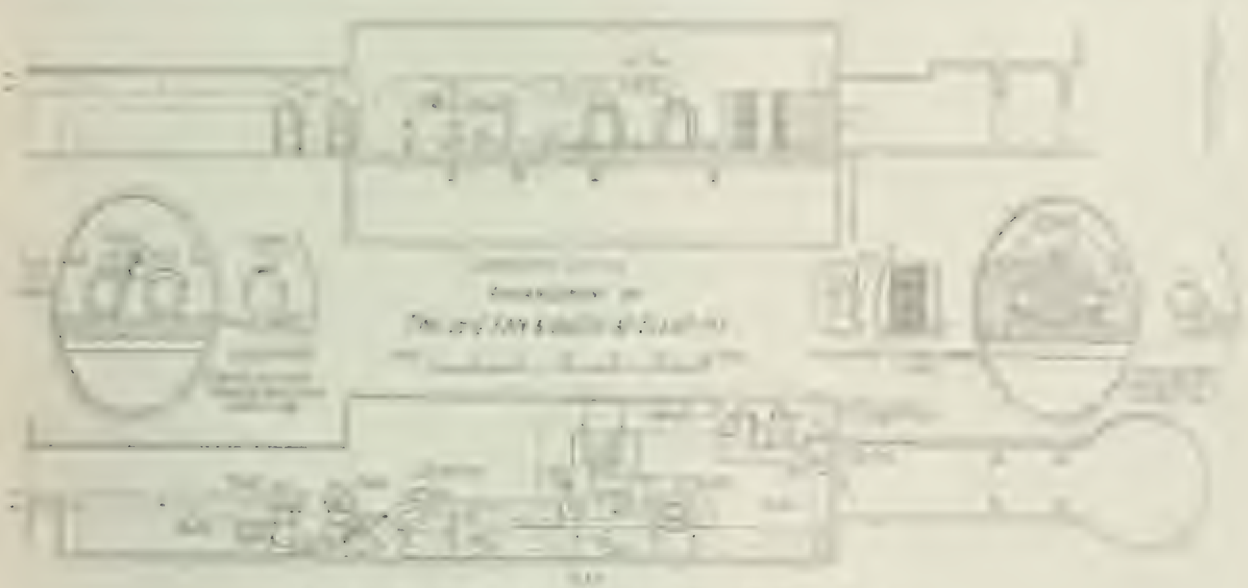


Fig. 21.—Ventilating Arrangement [illegible]

[illegible]

(Britannia Colliery)

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	—	[illegible]	[illegible]	[illegible]
[illegible]	Mather and Platt	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

liquid starts, [illegible] ture of the air which passes through the pump room at the rate of 10,000 cubic feet per minute.

[illegible]

and motors is shown in Fig. 24 and consists of oil tanks fitted with submerged "spur-wheel" pumps, chain-driven by small 3-phase motors mounted on the covers of the tanks and supplying oil to the various bearings. Each pump is fitted with an oil filter which can be withdrawn and cleaned while the pump is in action.

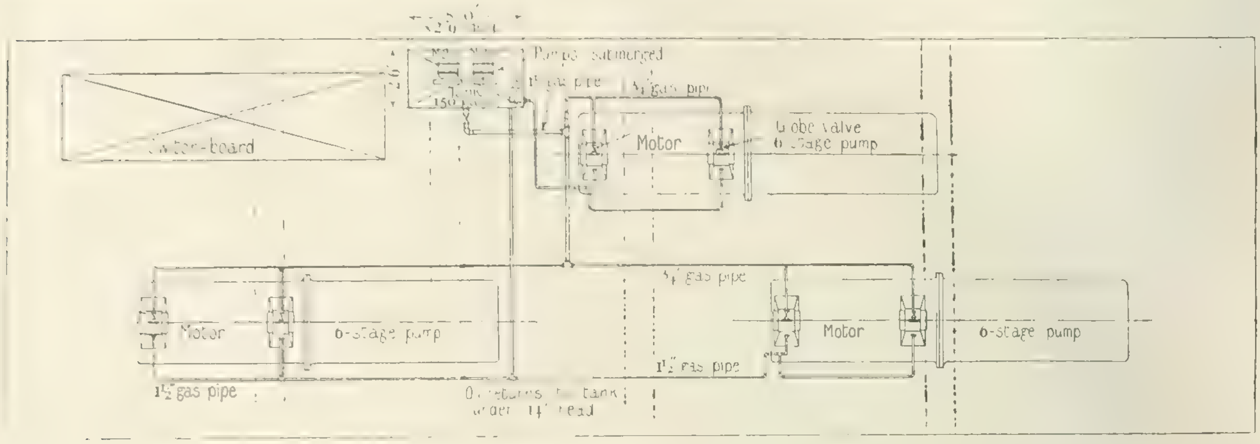


FIG. 24.—Lay-out of Elliot Pit Pumping Station.

The switchgear is of the totally enclosed cast-iron type. Duplicate feeders and busbars are used, arranged so that any feeder or pump motor can be connected to either feeder.

The water is discharged to the surface through two rising mains in the up-cast shaft, the mains being of 6 in. and 8 in. diameter respectively, and worked in parallel, or else through one 12 in. main in the down-cast shaft.

The overall efficiency of the above set tested at full duty was 71·9 per cent.

(*d*) VENTILATION.

Up to a few years ago the general colliery practice was to use low-speed fans; latterly a considerable number of centrifugal high-speed fans have been employed.

All the principal fans of the Powell Duffryn Company have duplicate motors as a stand-by to allow for cleaning and repairs. These fans are driven by induction motors, and in order to give flexibility in the volume of air the fans are rope-driven to allow the pulley ratio to be varied.

In deciding the size and speed of the motors two distinct problems have to be faced :—

(1) Replacing or supplementing existing steam drives working at full power.
(2) Opening out a new colliery.

In the first case any variation in speed that may be required is small, which can be met by inserting resistance in the rotor circuit. Where power is transmitted from a distance and a high power factor is of importance in order to keep down the cost of transmission mains, the power of such drives can be improved by using an exciter connected to the slip-rings on the Scherbius, Milch, or Kapp systems.

The second case is of a far more difficult character, as the speed range required during the first few years is large. The alternative drives in this case are :—

(1) Temporary rope drive using a small induction motor until the power and speed warrant the erection of a permanent motor.
(2) A continuous-current motor.
(3) A "Cascade" motor, giving two or three speeds.

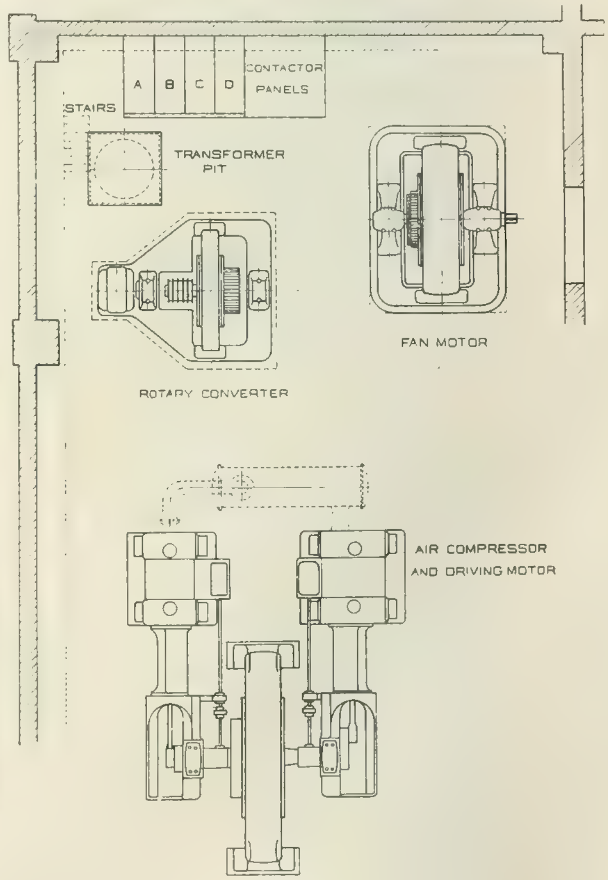


FIG. 25.—Fan-drive, Britannia Colliery.

A typical instance of continuous-current fan drive is shown in Fig. 25, which illustrates the plant supplied for

[illegible]

[illegible]

[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]

[illegible]

[illegible]

[illegible] is low, compared with electricity, compressed air is [illegible] plant on the surface or by isolated electrically-driven com- [illegible] workings.

Owing to the necessity of providing stand-by plant for each section, the difficulties due to grit in the compressor, [illegible] systems being interconnected so as to reduce the percentage of reserve plant.

As the air requirements are intermittent it is desirable to run the electrically-driven compressor or, when the demand is large, a part of the compressing plant equiva- [illegible]

[illegible] and increase the amount of wear and tear by running at constant speed, the air compressor being controlled by an [illegible] "Cascade" motors with an unloading device when the motor reaches its minimum speed.

[illegible] the same house, an efficient and satisfactory drive can [illegible]

[illegible]

[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

[illegible]

[illegible]

[illegible]

[illegible] and it will supply power for [illegible] tinuous-current motors for the [illegible] drive.

[illegible]

The motor has 16 [illegible] automatically varied by [illegible] to the air pressure in t[illegible] piston; this is actuated [illegible] compressor.

[illegible] by throttling the exhaust of the regulator. This adjustment makes it impossible for the motor to draw heavy [illegible] current or for the speed to vary within wide [illegible]

[illegible]

	[illegible]		
	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]

The maximum temperature rise of the motors and the rotary converter is 35 degrees C.

The figures for the compressor are as follows :—

Rating in cub. ft. of free air per min	Cub. ft. of free air per min. per b.h.p.
5,000	6·2
3,750	6·1
2,500	5·0

Compressor—Duty ... 2,500 cub. ft. of free air per min.

Pressure ... 70 lb. per sq. in.

	Full Load	Half Load.	1/10th Load.
Cub. ft. of free air per min. per b.h.p.	6·25	5·2	3·55

(*f*) Haulages.

Owing to the intermittent nature of haulage loads, the necessity for high torque at starting, and the tendency of all haulages to be used together towards the end of the shift, this load is one of the most costly to supply unless a large number of haulages are worked from the same power house.

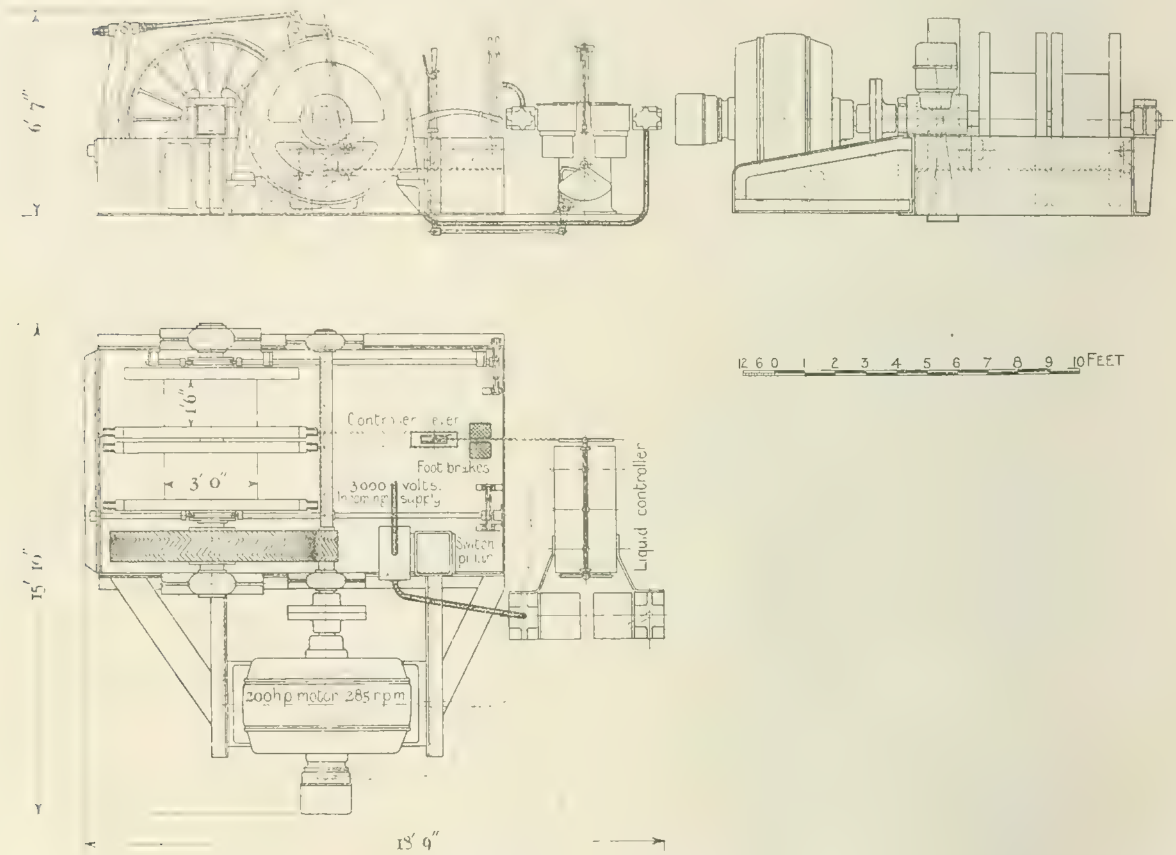


Fig. 26.—Single-reduction Haulage.

Abercwmboi.—The compressor is of the Belliss enclosed forced-lubrication type. Its capacity is 2,500 cubic feet of free air per minute at a pressure of 70 lb. per square inch, and it is driven by a 3-phase induction motor. The plant runs at a constant speed, the air pressure being governed by an unloading device.

The stand-by compressor at this point is driven by a 140 b.h.p. induction motor.

The larger compressor is of a similar type to the smaller compressor in use at the Britannia Pit.

		Full Load.	Half Load.
Motor—Rating	... 410 b.h.p.		
Speed	... 243 r.p.m.		
Efficiency	...	90·5 %	88 %
Power factor		78 %	62 %

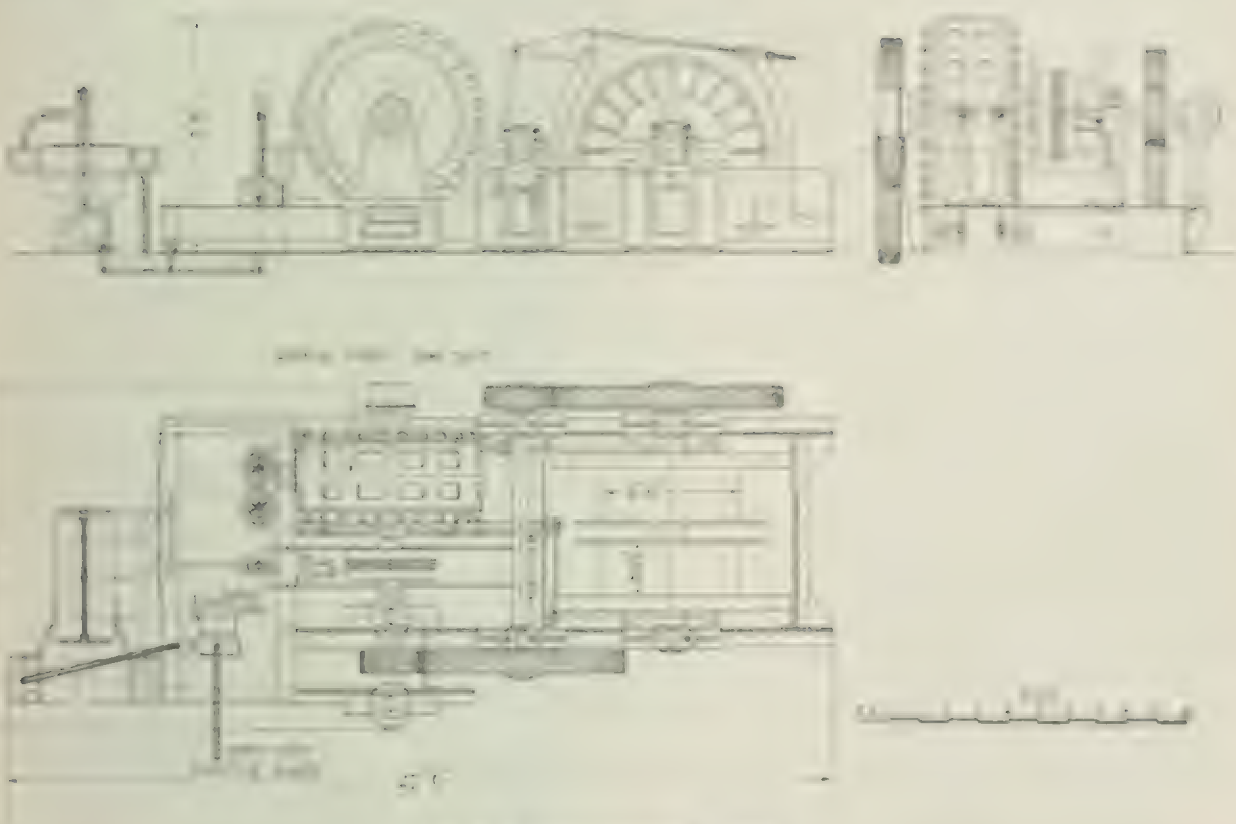
With steam or compressed-air haulage the speed of the journey on gradients decreases with increasing load.

With induction-motor drive, however, the speed is nearly constant, consequently the power demand is proportionately increased on gradients, thus decreasing the already poor load factor with this class of load.

Owing to the position of haulages it is undesirable to employ continuous-current motors, which involve with an alternating-current supply a special converting plant.

The usual form of drive is single-reduction gearing for the larger powers when room can be safely provided, and double-reduction gear for the smaller haulages or when space is limited.

[illegible]



[illegible] actuated.

The switch pillar and controller are mounted on the operating platform. The haulage driver has complete [illegible] the speed of the haulage drum being 30 r.p.m., and the [illegible]

[illegible] with the stator reversing-switch.

The liquid controllers consist of a tank [illegible] the [illegible]

carrying the tank and are mechanically connected to the lever or hand wheel operating the electrodes. The liquid is cooled by pipes through which water is circulated.

The chief advantages of the liquid type of controller are the finer adjustment of the speed, especially at starting when taking up slack on the rope and shackles, and its simplicity of design, resulting in fewer working parts and greater ease of inspection. The principal disadvantage is the necessity for a supply of cooling water. The latter difficulty can be overcome where no water is available by fitting a system of radiator cooling pipes and a small motor-driven centrifugal pump. While this method works satisfactorily, it adds considerably to the first cost.

Owing to the heavy duty imposed on reversing switches of both types of controllers a special design is called for, as the frequency of operation under conditions of maximum load is much higher than that required from any other switch. To prevent overheating and formation of carbon deposit it has been found necessary to design these switches on generous lines, with an increased area of contact and a big head of oil as compared with standard switches of the same rating.

(*g*) Small Surface Motors.

The smaller motors up to 30 b.h.p. used for driving the various auxiliaries on the surface do not call for special notice. The motors are of the standard protected 3-phase type wound for 500 volts. The majority of them have slip-ring rotors with liquid resistances for starting, this type of rotor being preferable to the squirrel-cage type on account of the reduced switchgear maintenance.

Normally these motors are handled by unskilled labour, and in consequence the switchgear should be as simple as possible.

Lighting.

(*a*) *Underground.*—This is confined to the immediate pit bottoms, and the haulage and pump rooms. The standard pressure is 110 volts, carbon-filament lamps being used.

The conductors are single rubber-insulated cables in stout, screwed, metal conduits, and are controlled by switches and fuses in cast-iron watertight boxes, all lamps being enclosed in watertight fittings.

The switches and fuses for the upcast shaft are fixed in the main air ways.

(*b*) *Miners' safety lamps.*—The introduction of the metal-filament lamp has made the use of portable electric miners' lamps possible, and every improvement in the efficiency of the lamp has extended their use. Apart from the increased safety in the presence of gas, the electric hand-lamp decreases the risk of accident through improved illumination.

The Powell Duffryn Company have now between seven and eight thousand miners' electric lamps in use, or about two-thirds of the total. These lamps weigh about $5\frac{1}{2}$ lb. each, compared with $3\frac{3}{4}$ lb. for the standard oil safety lamp, and they are welcomed by the miners, who prefer the additional illumination in spite of the additional weight.

The lamp batteries are charged in groups of 40 for lead and 26 for alkaline batteries by 110-volt continuous-current motor-generators, each charging stand having an ammeter and a variable resistance for adjusting the current.

At the larger collieries charging boards capable of holding 1,000 batteries are used, the lamps being stored in a standard rack in the lamp room when charged.

In the first instance the lead batteries were charged in 7 hours, which is now extended to 12 hours. During charge the lead batteries are inspected to see that they are gassing, and on the completion of the charge the pressure of each is tested by a portable voltmeter.

With normal charging, the lamp will burn 12 to 14 hours. The candle-power is between 1 and $1\frac{1}{2}$, depending upon the condition of the battery and the type of bulb; whereas the ordinary oil safety lamp gives 0·5 to 0·6 candle-power.

The energy required for charging is of minor importance, and the cost of attendance for charging and cleaning the electric lamps is comparable with the cost of the daily attention necessary in the case of ordinary oil lamps. The important part of the cost is the maintenance of the battery and the lamp bulbs. In the case of the lead battery, the cost of lamp renewals equals the cost of battery maintenance.

Two types of battery are used. With the original lead type the positive plates lasted about 9 months; new positive plates were then inserted to run a further 9 months, before the negative plates required renewal. Improved positive plates are now on trial, and it is hoped that they will last 18 months.

The main point necessary for success with the lead type of battery is the non-spilling of acid. Cleanliness is everything.

The alkaline type of battery is now under trial. Although these are twice as expensive as the lead type, their life is very much longer. Sufficient time has not yet elapsed, however, to allow the life to be definitely determined, but the makers give it as 15 years.

When it is possible to use lamps of the half-watt type, the useful field for miners' lamps will be much extended, as the batteries will then have to be charged only half as often as at present, with consequent decreased wear and tear, or, alternatively, increased light will be obtainable without adding to the weight.

In addition to the miners' lamp a second type is being tried for officials and hauliers. In this case the battery is strapped to the man's back and the lamp is fixed in his cap so as to leave both hands free.

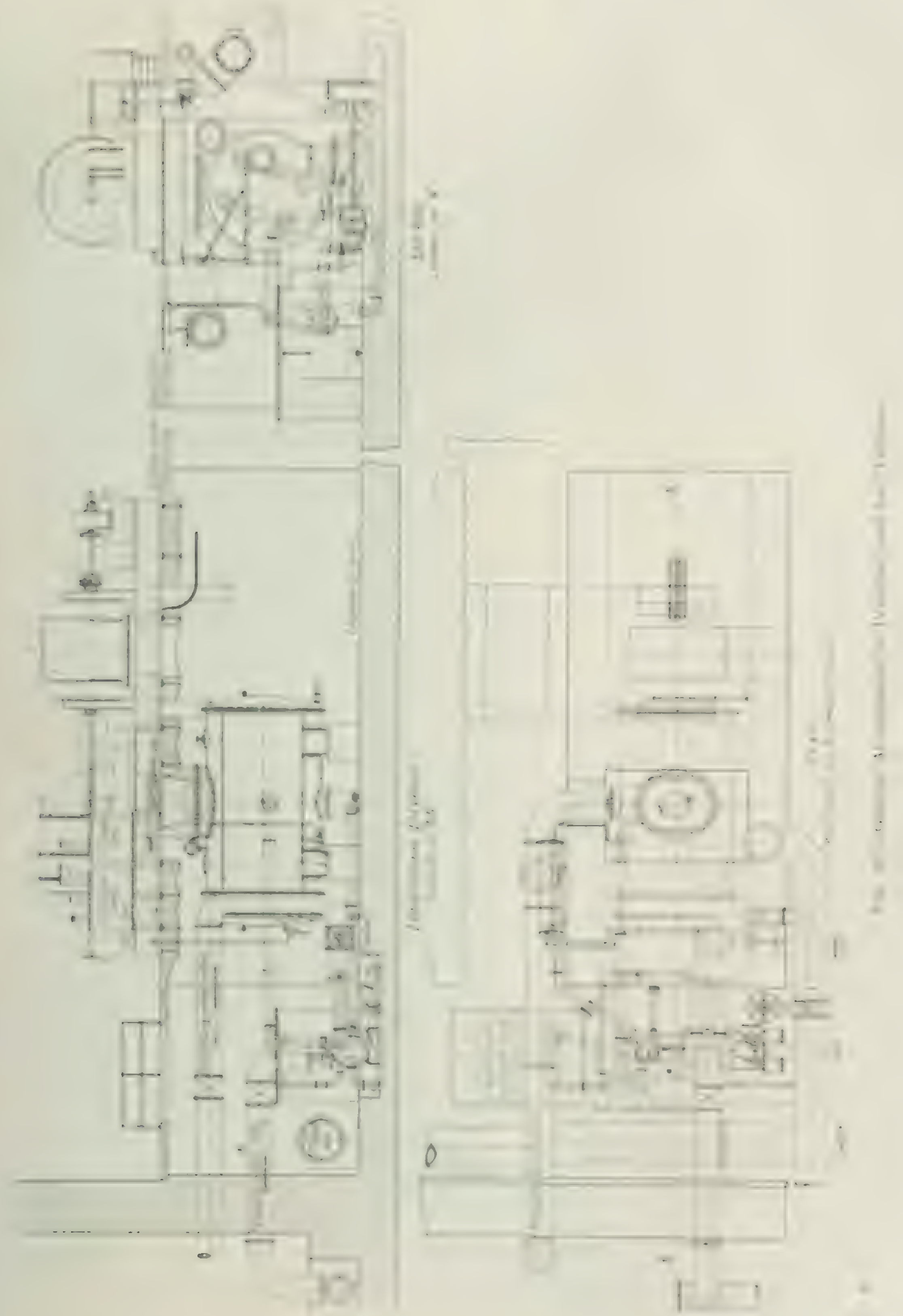
In all positions where there is danger of gas the present type of electric lamps has to be supplemented by oil safety lamps, so that there may be a clear indication of danger.

Electric Signalling.

The increasing size of colliery undertakings and the use of haulages renders electric-bell signalling important. This system has been in use about 25 years, and while its reliability in signalling over comparatively long distances has led to a decrease in the number of accidents, its safety has been questioned during the last two years.

Under the Special Rules* issued in 1905, Regulation 53 permitted the use of bare signalling wires in haulage roads when the pressure in any circuit did not exceed 15 volts, and by Regulation 137 (*b*) all such systems in use before the 1st June, 1911, were allowed to be continued in use

* Coal Mines Act, 1887. Special Rules issued in 1905.



until the 1st June, 1920, unless the local Inspector raised objection. This permission has been withdrawn in some cases in South Wales.

Regulations 132 and 134 (a) allowed the use of a pressure not exceeding 25 volts on bare signalling wires when there was no risk from "open sparking," the onus of determining the point where such sparking becomes dangerous being placed on the mine owner, agent, or manager. In view of the difficulty of determining this point, the Regulations require amendment, as recommended by H.M. Chief Inspector on the 31st March, 1914. When the Regulations* were issued in 1913 little was known of the danger point.

Reference to the work of Dr. W. M. Thornton † of April 1910 and October 1912 shows that currents large in comparison with those used in bell circuits could be used with safety in the presence of pit gas (fire damp). These tests also show that the ignition point with explosive mixtures of pit gas requires the use of larger currents than with explosive mixtures of chemically-prepared methane or town gas.

measured) quite disproportionate to that used for signalling purposes.

Following the explosion at the Senghenydd Colliery in October 1913, a series of tests were made by the Home Office officials in January 1914 at the New Tredegar Rescue Station, South Wales, at which the author was present representing the colliery owners; and by permission of Mr. R. T. Rees of the Lewis Merthyr Colliery Company, who own the Senghenydd Colliery, the summarized results of these tests are given in Appendix II.

The signalling system in use at Senghenydd had been erected prior to June 1911 (when the maximum pressure allowed in signalling circuits was 15 volts). There was a dispute as to the number of dry cells in use on the signalling circuits at the time of the explosion, but in no material case did it exceed nine. The battery boxes in some instances contained 10 dry cells, but on the short signalling circuits the number of cells connected varied from six to nine.

Tests of the ignition point of explosive mixtures of pit and lighting gas and air were made at the New Tredegar

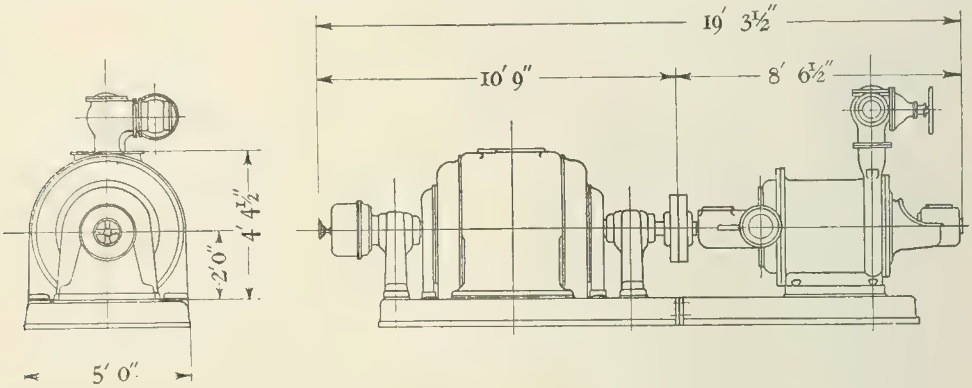


FIG. 29.—Elliot Pit 1,000 b.h.p. Centrifugal Pump.

Following an explosion of fire damp in the South Wales district in 1912, a notice was issued by the Home Office calling attention to the necessity of strict observance of the Electrical Special Rule 15 (1) with reference to signalling apparatus. The notice stated—

" . . . The explosion was proved beyond reasonable doubt to have been caused by the sparking of an electrical signalling bell, which ignited an accumulation of gas, resulting from a derangement of the ventilation due to the breakage of air pipes.

"It was afterwards proved experimentally that sparks from the bell in question, worked by a battery of 11½ volts would ignite an explosive mixture of lighting gas and air; and the mixture was also ignited by sparks from signalling wires produced by a current of only four volts pressure. . . ."

It will be noted that these tests were made with an explosive mixture of lighting gas and air, which is ignited with much lower currents than pit gas. The second test at 4-volts pressure was made with an accumulator, which, owing to its low internal resistance gave a current (not

Rescue Station in January 1914 with three bells. These bells were fitted with iron cases (not gas-tight), and dry batteries were directly connected to the bells by a few feet of signal wire, the batteries being new and the length of the signal wire in use being from 46 to 656 yards.

The signalling wires used at Senghenydd were No. 7 and No. 8 S.W.G. galvanized iron wire, the resistance per mile of lead and return (without joints) of No. 8 S.W.G. being 26 ohms, and of No. 7 S.W.G. 21·5 ohms.

Bell No. (1) from Mafeking Hard Heading, drum engine-house, Senghenydd.

Bell No. (2) from Mafeking Hard Heading, No. (2) engine-house, Senghenydd.

Bell No. (3) a bell belonging to the New Tredegar Rescue Station.

The following tests have been made of the characteristics of dry cells and of the above bells :—

Average open-circuit E.M.F. of "Dania"—type C—dry cell	1·53 volts
Average internal resistance at 49° F. ...	0·26 ohm
Bell No. (1) resistance	7·59 ohms
Bell No. (2) „	7·79 „
Bell No. (3) „	3·82 „

* Coal Mines Act, 1911. General Regulations issued July 1913.

† W. M. THORNTON. Ignition of coal-gas and methane by momentary electric arcs. *Transactions of the North of England Institute of Mining and Mechanical Engineers*, vol. 63, p. 17, 1912–13.

[illegible]

[illegible]	[illegible]			
	[illegible]		[illegible]	
	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]		[illegible]	
[illegible]	[illegible]		[illegible]	
[illegible]	[illegible]		[illegible]	
[illegible]	[illegible]		[illegible]	
[illegible]	[illegible]		[illegible]	

[illegible]

	[illegible]	[illegible]	[illegible]
		[illegible]	[illegible]
Bell No. (1)	6	[illegible]	[illegible]
	7	[illegible]	[illegible]
	8	[illegible]	[illegible]
	9	[illegible]	[illegible]
Bell No. (2)	6	[illegible]	[illegible]
	7	[illegible]	[illegible]
	8	[illegible]	[illegible]
	9	[illegible]	[illegible]
Bell No. (3)	6	8·28	[illegible]
	7	[illegible]	[illegible]
	8	[illegible]	[illegible]
	9	[illegible]	0·92

[illegible] per cent.

[illegible] these tests were sufficiently exhaustive to settle the safe limit, further tests were made at his request by Dr. Wheeler * at which the colliery owners were not represented. The following is an extract from the Home Office report, Cd. 7346, pp. 36–40.

[illegible]

"[illegible] remove traces of acetylene—and over 'oxydized' palladium [illegible] 2 per cent nitrogen."

[illegible]

[illegible]

No. of cells required for ignition by [illegible]

Current on closed circuit ... ... 0·70 ampere

[illegible]

[illegible] Leclanché cells is referred to. To secure ignition with Leclanché cells by "break flash" the pressure had to be increased.

"A bell [illegible]

"A bell lent by [illegible] compared with [illegible]

From these tests Dr. Wheeler deduces "That if the current flowing round the signalling circuit could be [illegible]

It will be noted that the [illegible]

* [illegible]

regards resistance and inductance from those of the bell referred to in Dr. Wheeler's Report as "a bell from Senghenydd," and that the current in the Senghenydd bell circuit under the conditions of the tests made in January 1914 with the bell directly connected to 9 cells with a few feet of signalling wire was :—

	No. of Dry Cells	Closed Circuit P.D. of Battery. Volts	Bell-ringing Current. Amperes
Bell No. (1)... ...	9	13·73	0·32
Bell No. (2)... ...	9	13·73	0·37

This shows that the current in the bell circuit in the case of cells actually in use at the colliery, without allowing for any reduction due to the resistance of the signal wires in circuit, closely approached the safe limit suggested by Dr. Wheeler for chemically-prepared methane, viz. 0·3 ampere.

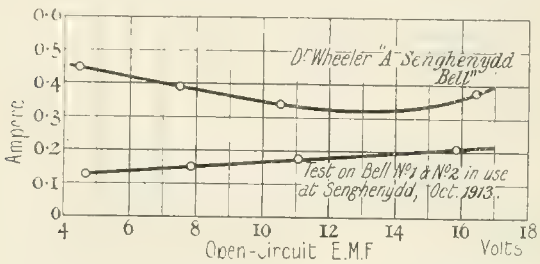


FIG. 30.—Curves showing Results of Dr. Wheeler's Tests on "A Senghenydd Bell" (Home Office Report, p. 37, Cd. 7346), and Tests of current measured by hot-wire ammeter with Senghenydd Bells Nos. (1) and (2) under similar conditions as to circuit.

Fig. 30 gives a comparison of Dr. Wheeler's tests on a bell from Senghenydd made with similar pressures and with additional resistance, and the bells Nos. (1) and (2) actually used at Senghenydd.

The following results are summarized from the Senghenydd tests, January 1914, Schedule (2) attached :—

	Ignition. Volts	No Ignition. Volts
Tests Nos. (1), (2), (3), (4), (5), (8), (10), (11), 29 *January*, 1914. No ignition could be secured with an explosive mixture of pit gas and air by a "break flash" on a short length of signalling wire in series with No. (1) bell with voltages from	—	8·8 to 11·9
Tests Nos. (9) *and* 11, 1 *January*, 1914. A "break flash" from signal wires fired an explosive mixture of Cymmer Pit gas and air with bell No. (2) directly connected to 9 dry cells by short signalling wires. Pressure	13·5	—
Test No. (12), 29 *January*, 1914. A "break flash" from signal wires fired an explosive mixture of Cymmer Pit gas and air with bell No. (3) directly connected to 8 dry cells by short signalling wires. Pressure	11·9	—
Test No. (14), 1 *January*, 1914. No. (2) bell "contact" fired an explosive mixture of Cymmer Pit gas and air, when connected to 15 dry cells by short signalling wires. Pressure	22·5	—
Tests Nos. (1), (2), (6), (7), (8), 1 *January*, 1914. No ignition of explosive mixture of pit gas and air could be secured from "contacts" of bells No. (1) or No. (2) up to	—	13·5
Tests Nos. (7), (13), (14), (15), 29 *January*, 1914. No ignition could be secured with explosive mixture of pit gas and air from bell "contacts" with Nos. (1), (2), or (3) bells, with voltages from	—	8·7 to 11·5
*Summarized Results of Dr. Wheeler's Tests.**		
With "a bell from Senghenydd" a "break flash" from a mechanically-driven breaker fired an explosive mixture of chemically-prepared methane and air when the bell was directly connected to dry cells	4·5	—
The bell "contact" of a bell lent by Professor Thornton when in series with a mechanically-driven "contact" breaker fired an explosive mixture of chemically-prepared methane and air when directly connected to dry cells	7·5	—

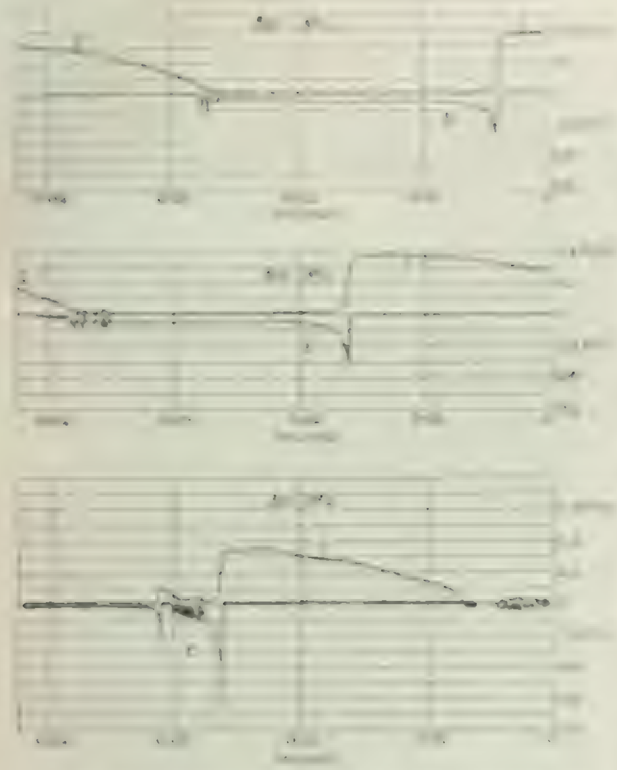
All these tests show that the principal danger point is the signalling wires, which are usually bare galvanized iron wire, the lead and return wires being run on insulators, signals being given from any desired point by pressing the wires together or by connecting them by metal bar, file, or knife.

Fig. 31 shows oscillograph records recently obtained at Faraday House across the contacts of bells (1) and (2), the bell being connected in each case to six "Dania" dry cells in series with a resistance of 10 ohms. These records were selected out of a number taken, in order to show the maximum pressure across bell contacts at the moment of breaking and making the circuit.

With a cell pressure of 9 volts on open circuit, a momentary pressure of 80 volts was reached with bell

* See page 421.

[illegible]

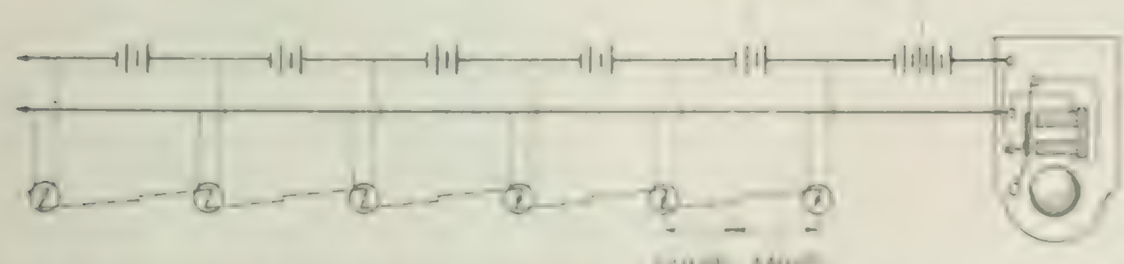


[illegible]

[illegible] to short-circuiting of the signal wires near the bell station, [illegible]

	[illegible]	[illegible]
Winding	[illegible]	[illegible]
Pumps—[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
Fans	[illegible]	[illegible]
Haulage—[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
Washers	[illegible]	[illegible]
Air compressors	[illegible]	[illegible]
Miscellaneous motors used for surface work	[illegible]	[illegible]
Total	[illegible]	[illegible]

[illegible]



[illegible]

only sufficient cells being located near the bell to secure [illegible]

There are several alternative systems for securing safety.

[illegible] so that they must be replaced when run [illegible]

(5) Signals to be made by switches actuated by a "pull" wire, the switches being enclosed in rigid metal, the covers being flame-tight, and the switch contacts breaking contact through non-inductive resistances contained in the same metal case as the switch.

For long-distance signalling (B), a high-resistance relay with a shunted contact and enclosed in a flame-tight, rigid, metal case should be used, the shunt resistance being inside the relay case. Where this is done the line pressure can be kept down to 6 volts.

Alternatively the alternating-current system should be adopted, the same system of wiring and switches being used as under (A). This system has the advantage of getting rid of battery maintenance. The transformer pressure should be 15 volts, and the bells should have their coils enclosed in rigid metal.

Main Advantages of Electric Driving of Collieries.

(1) Economy in the cost of power by concentrating the steam plant at a central point.
(2) Facility for meeting additional power requirements.
(3) Reduced maintenance.
(4) Improved working conditions underground.

Conclusion.

My best thanks are due to Mr. Joseph Shaw, K.C., the Chairman of the Powell Duffryn Steam Coal Company, Ltd., for permission to publish the details of their electrical undertaking; also to Mr. G. G. Hann, Assistant General Manager of the Company, who has materially assisted me in the preparation of this paper, and to the various contracting firms who have given every assistance in providing drawings and details of the plant.

APPENDIX I.

Penallta.

Details of two tests made at the Penallta Colliery of the Powell Duffryn Steam Coal Company, on a Babcock & Wilcox boiler fitted with a superheater and chain-grate stokers for burning small Welsh coal.

	Test (1)	Test (2)
1. Test number	1	2
2. Date of test	2/1/13	4/3/13
3. Duration of test	6 hours	6 hours
4. Boiler heating surface ...	7,330 sq. ft.	7,330 sq. ft.
5. Superheater	1,650 ,,	1,650 ,,
6. Grate area	144 ,,	144 ,,

Coal.

	Test (1)	Test (2)
7. Kind used	Penallta slack (unwashed)	Elliot duff (washed)
8. Total quantity fired ...	19,152 lb.	23,807 lb.
9. Consumed per hour ...	3,192 ,,	3,968 ,,
10. Consumption per sq. ft. of grate area per hour ...	22·16 ,,	27·5 ,,
11. Analysis—		
Moisture	0·82 %	8·28 %
Volatile matter... ...	13·41 %	11·46 %
Fixed carbon and sulphur	66·05 %	73·98 %
Absolute ash	19·72 %	6·28 %
	100·00 %	100·00 %
12. Calorific value as fired	11,968 B.Th.U.	12,614 B.Th.U.

Steam.

	Test (1)	Test (2)
13. Average gauge pressure ...	144 lb.	149 lb.
14. Temperature of saturated steam	363° F.	365° F.
15. Temperature of superheated steam	606·5° F.	587° F.
16. Superheat	243·5° F.	222° F.

Water.

	Test (1)	Test (2)
17. Feed-water temperature ...	78° F.	97° F.
18. Total water evaporated ...	133,488 lb.	178,824 lb.
19. Average evaporation per hour, actual	22,248 ,,	29,804 ,,
20. Average evaporation per hr. from and at 212° F. ...	29,367 ,,	38,506 ,,
21. Evaporation per sq. ft. of heating surface from and at 212° F....	4 ,,	5·24 ,,
22. Evaporation per lb. of coal as fired, actual	7 ,,	7·51 ,,
23. Evaporation per lb. of coal as fired from and at 212° F.	9·2 ,,	9·70 ,,
24. Factor of evaporation, including superheat ...	1·32	1·292

Flue Gases.

	Test (1)	Test (2)
25. Temperature at boiler damper	478° F.	508° F.
26. Average amount of CO_2 ...	10·4 %	11·3 %
27. Draught at boiler damper (induced fan)	0·9 in.	0·8 in.

Efficiency.

	Test (1)	Test (2)
28. Boiler, superheater, and stoker	74·25 %	74·3 %

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

[illegible]

11.44	—	—	No ignition	—

Test No. (4).

[illegible]

11.47	—	—	[illegible]	[illegible]

Test No. (5).

[illegible]

11.50	—	—	[illegible]	

Test No. (6).

[illegible]
Bell No. (2), Senghenydd.
[illegible]

12.11	Taper passed into chamber to see that [illegible]			
12.20	4 Series of 3 to 6 signals		No ignition	[illegible]
[illegible]	Continuous signals	[illegible]	—	[illegible]
[illegible]	—	[illegible]		

APPENDIX II—*continued.*

TEST NO. (7).

Number of cells = 9. Pressure = $13\frac{1}{2}$ volts.
Other conditions as in Test No. (6).

Time p.m.	Method of Making Contact	Period of Experiment Min.	Sec.	Result	Notes
12.31	11 Series of 6 signals	—		No ignition	Mixture tested—O.K.

TEST NO. (8).

As in Test No. (7) but cover taken off bell.

Time p.m.	Method of Making Contact	Min.	Sec.	Result	Notes
12.39	6 Series of 6 signals	0	20	No ignition	Mixture tested—O.K.
	Continuous ringing	1	45	,,	9 to 10 per cent gas—K.
		0	25	,,	
		1	26	,,	
		3	56		

TEST NO. (9).

Number of cells = 9. Pressure = $13\frac{1}{2}$ volts.
Bell No. (2), Senghenydd.
Signal wire—No. 11 S.W.G. galvanized.
Apparatus in testing chamber—signal wires hung vertically.

Time p.m.	Method of Making Contact	Min.	Sec.	Result	Notes
12.47	Signal wires bridged by steel contact-maker with sharp V edge	0	30	Ignition after 30 seconds	Contact made by rubbing V contact-maker up and down wires. Contact-maker at top of chamber when ignition occurred by screws

TEST NO. (10).

Same conditions as Test No. (9).

Time p.m.	Method of Making Contact	Min.	Sec.	Result	Notes
12.56	Signal wires bridged	1	45	No ignition	Gas pressure, 1·1 in.
	by steel contact-	1	20	,,	Mixture tested—O.K.
	maker with sharp	2	25	,,	
	V edge	2	30	,,	
		0	15	,,	
		2	10	,,	,, ,, ,,
		0	55	,,	
		0	30	,,	
		1	40	,,	Gas pressure, 1 in.
		0	40	,,	
		12	10		

TEST NO. (11).

Signal wires changed for new set No. 11 S.W.G. as first set worn flat by contact-maker.

Time p.m.	Method of Making Contact	Min.	Sec.	Result	Notes
1.17	Signal wires bridged	2	5	No ignition	Gas mixture tested—O.K.
	by steel contact-	0	5	,,	
	maker with sharp	0	20	Ignition	Mixture fired when contact-maker 3 in. from bottom of chamber
	V edge				
		2	30		

(13 Tests = 14 min. 40 sec.)

TEST NO. (12).

Number of cells = 9. Pressure = $13\frac{1}{2}$ volts.
Bell No. (2), Senghenydd, without cover, replaced in testing chamber.

Time p.m.	Method of Making Contact	Min.	Sec.	Result	Notes
1.34–1.37	17 Series of 6 signals	1	0	No ignition	Gas pressure, 12 in. Gas mixture tested—O.K. Bell trembler, $\frac{1}{3}$ down chamber
1.43	6 do. do.	1	45	,,	Gas mixture tested—O.K.
	Continuous ringing				Bell moved up and down
		2	45		

(Test on bells discontinued.)

APPENDIX II.—continued.

Test No. [illegible]

[illegible]

Time a.m.	Method of making contact	Time of experiment Min. Sec.	Result	Notes
[illegible]	6 Signals	—	No ignition	[illegible]
	7 do.	—	[illegible]	

Test No. (14).

[illegible]

[illegible]	Succession of signals	—	[illegible]	[illegible]

Test No. [illegible]

[illegible]

—	[illegible] Signals	—	No ignition

[illegible]

Test No. (1).

[illegible]
No resistance in circuit to represent signalling line.
[illegible]

Time a.m.	Method of making contact	Time of experiment Min. Sec.	Result	[illegible]	Notes
10 31	Wires pressed together	[illegible]	No ignition	[illegible]	[illegible]

Test No. [illegible]

10 50	Signal wires bridged by No. 11 S.W.G. galvanized wire	[illegible]	No ignition	[illegible] continuously	[illegible]

Test No. [illegible]

11 7	Signal wires bridged by shovel, to represent [illegible] edge	[illegible]	No ignition	[illegible] mum sparking	[illegible]

APPENDIX II—*continued*.

Test No. (4).

Time a.m.	Method of Making Contact	Period of Experiment Min.	Sec.	Result	Notes	Notes
11.31	Signal wires bridged by steel contact-maker with sharp V edge	5	37	No ignition	Intermittent contact made continuously to produce maximum sparking	Room, 61° F.; testing chamber, 61–62° F.
		5	13	,,		Mixture tested and found explosive 5 times. A
		3	49	,,		Volts, 8·9
		2	53	,,		
		8	7	,,	,,	
		25	39			

Test No. (5).

Time	Method of Making Contact	Min.	Sec.	Result	Notes	Notes
p.m. 12.1	Signal wires bridged by half-round file. Contact made with point of file on one wire flat on the other	0	41	No ignition	Intermittent contact made continuously to produce maximum sparking	Mixture tested and found explosive
		0	55	,,		Volts, 8·9.
		0	55	,,		
		2	31			

Test No. (6).

New set of signal wires, hung vertically in testing chamber—No. 11 S.W.G. galvanized.

Time	Method of Making Contact	Min.	Sec.	Result	Notes	Notes
12.7	Sharp V edge	5	0	No ignition	Intermittent contact made continuously to produce maximum sparking	Mixture tested at frequent intervals and found explosive
	File	3	51	,,		Gas pressure, 1·1 to 1·05 in.
	Shovel	0	33	,,		Volts, 8·9
	Sharp V edge	5	10	,,		
	Shovel	1	4	,,	,,	
	Sharp V edge	3	52	,,	,,	
	,,	1	15	,,	,,	
	,,	11	43	,,	,,	
12.43		32	28			Gas cylinder exhausted

Test No. (7).

Battery as before = 6 cells. Pressure = 8·9 volts.
Bell No. (2), Senghenydd.
Signal wires No. 11 S.W.G. as used in Test No. (6).
Apparatus in testing chamber—bell, without metal cover, bell contact 8 in. from top of chamber.

Time	Method of Making Contact	Min.	Sec.	Result	Notes	Notes
1.20	Continuous contact	1	45	No ignition	Bell ringing continuously	Gas pressure, 0·9 to 0·95 in.
		1	21	,,		Volts when ringing, 8·9
		0	45	,,	,,	Mixture tested and found explosive 5 times. K
		0	53	,,	,,	Sparking of bell contact observed
		1	23	,,	,,	
		6	37			

Test No. (8).

Conditions as Test No. (1).
New Signal Wires, 3rd Set, size as in Test No. (6).
New Signal Wires in chamber, hung vertically.

Time	Method of Making Contact	Min.	Sec.	Result	Notes	Notes
1.39	Signal wires bridged by steel contact-maker with sharp V edge	3	33	No ignition	Intermittent contact made continuously to produce maximum sparking	Testing chamber, 57° F.
		2	20*	,,		Mixture tested and found explosive 4 times. K
		1	40†	,,		Gas pressure, 1 in.
		2	55	,,		
		10	38			

* Mixture ignited with taper 2 in. from bottom of testing chamber.

† Polarity of wires reversed.

APPENDIX II—[illegible]

Test No. [illegible]

[illegible]

[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]
[illegible]	Signal wires bridged by [illegible] V edge	[illegible]	[illegible]	[illegible]	[illegible] to produce [illegible]	[illegible]

[illegible]

Test No. [illegible]

[illegible]

[illegible]	Signal wires bridged [illegible]	[illegible]	[illegible]	No ignition	[illegible]
		[illegible]	25		[illegible] etc. A [illegible]

[illegible]

Test No. [illegible]

[illegible]

[illegible]	Signal wires bridged by steel contact-[illegible] V [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Test No. [illegible]

[illegible]

[illegible]	Signal wires bridged by steel contact-[illegible] V [illegible]	[illegible]	[illegible]	[illegible] nited at [illegible]	—	[illegible] ignited. Contact [illegible]

Test No. [illegible]

[illegible]

2.45	Continuous contact	[illegible]	[illegible]	[illegible]	[illegible]

APPENDIX II—*continued.*

TEST NO. (14).

Number of cells = 7. Pressure = 10 volts.
Otherwise conditions as Test No. (13).

Time p.m.	Method of making Contact	Period of Experiment Min.	Sec.	Result	Notes	Notes
—	Continuous contact	0	46	No ignition	—	—

TEST NO. (15).

Number of cells = 8. Pressure = 11·5 volts.
Otherwise conditions as Test No. (13).

Time p.m.	Method of making Contact	Period of Experiment Min.	Sec.	Result	Notes	Notes
2.53	Continuous contact	0	55	No ignition	—	—

DISCUSSION BEFORE THE INSTITUTION, 25 FEBRUARY, 1915.

Mr. Merz

Mr. C. H. MERZ: I suppose that up to the present time the paper which the author read before the Institution in 1905 has been considered the standard paper on colliery electrification; and it has now been brought up to date by the present paper. The author gives an account of what, I suppose, is the most complete, certainly the largest, system of colliery electrification in this country. No doubt there are collieries in other districts which depend more completely on electricity, but they do not use such a large amount of power. The Powell Duffryn installation has the great advantage that one engineer has dealt with it from the generating station right down the pit to the machines themselves, so that we have a complete and unified system standardized throughout, not only in regard to its main features of voltage and frequency, but also no doubt in many of the details of the machines themselves. This work has been done—and this is an important point—without Parliamentary powers of any kind, and therefore it has made great progress. Not only has the author completed this very great work, but he has also done some things which a great many of us have been wishing to do for some time, and perhaps have only done partially or not at all. For instance he has used gas engines successfully, and, as we see under the conditions in which he has used them, advantageously so far as the resulting thermal efficiency is concerned. The author made some very pertinent remarks in regard to the supply of energy to collieries, and I think he could not have put the position more fairly, so far as a supply from electric power companies is concerned. It might be added, however, that in every case where a connection to an electric power company's system is possible it should prove advantageous, even if only as a stand-by. One of the chief economies in such a case would be, or ought to be, a saving in the capital cost of distribution. In this country there are very few electric transmission lines of which the capacity could not be doubled or trebled at a very small percentage increase in the cost. It therefore follows that wherever there are two or more circuits covering the same ground, one say belonging to a group of collieries and the other to a power company, it must be profitable to combine them. It is interesting but unfortunate that in South Wales the power company's system has a different frequency from that of the Powell Duffryn electrical plant, and I am afraid that there it will be impossible for the two systems to be connected. The author also makes some pertinent remarks on the question of the complete electrification of collieries. He states that complete electrification is seldom justified if the colliery is equipped with main steam winders. I think that as electrical engineers we may confidently look forward to further progress in this respect not only on the South Wales system but on all systems, with the result that the complete electrification of colliery plant will be justified in all cases. I look upon the exhaust-steam turbine as a temporary expedient—as a useful means of getting over a transition period, but nothing more. We all appreciate that electrical engineers in the early days—at any rate in this country where there is very little water power—had to commence by driving their dynamos by means of the existing prime-movers, which latter were unsuitable for the purpose, having been developed for driving quite different forms of machinery. The main steam winders to which the author refers are a remnant of the old form of engine. It has been improved at the low-pressure end by adding the exhaust-steam turbine, but it cannot be improved at the high-pressure end in that way. As we get prime-movers more and more developed and adapted for the primary purpose of generating power, and in which the development or design is not controlled at all by the machines or the apparatus that they have to drive, we can utilize more and more efficient thermodynamic cycles and therefore obtain a higher efficiency. There is no doubt that the recent practice of using higher pressures and greater superheats will tend more and more to the best economy only being obtainable in prime-movers the speed and other characteristics of which are independent of the machinery to be driven. That is only possible when they drive dynamos or alternators and not where the prime-mover has to be applied directly to the machine or apparatus where the power is required. The thermal efficiencies of gas and steam plant given by the author are exceedingly interesting and they show, what is generally realized now, that in comparatively small units the gas engine is much more efficient. If, however, we consider the largest sizes it would of course be possible to attain the gas engine efficiencies by steam plant. The information that the author gives in regard to earthing will be

[illegible]

... given in the paper in regard to the use of bells and [illegible]

Mr. S. [illegible] ... coal-field goes back nearly 30 years. In those days [illegible]

... engineers because it marks the enormous progress already made by the introduction of electricity into mining. I remember that when the author read his previous paper before the Institution eight or nine years ago * there was a certain amount of nervousness, a little timidity perhaps [illegible] ... has very largely dis-appeared and to-day colliery owners are aware of the fact [illegible] ... provided the installation is carried out on proper lines. I propose to confine my remarks to that section of the paper which relates to electric signalling. The common [illegible] ... great deal of attention was concentrated on that bell some of us think attention was riveted on the bell in order

[illegible]

... volatilized we shall have, in addition to the [illegible] ... metal is scattered and constitutes a more serious danger than the spark itself. Now under what conditions [illegible] ... would go a little further and suggest that the nearer the [illegible] ... succeeded in making a commercial success of it because [illegible]

Mr. Evershed.

tight case, in which their coal-cutting motor was enclosed, was filled with an explosive mixture of coal-gas and air. When the commutator brushes were set so that the machine was working properly—by no means sparklessly in those days—it was quite impossible to produce an explosion no matter how long the machine was run. But the moment the brushes were shifted so that, in addition to the sparks under the brushes, an external flash was produced, then an explosion at once resulted. The reason is clear. So long as the sparks were occurring under the brushes, between the brushes and the commutator, the burning of the gas was restricted, but the moment a flash was produced outside where there was no cold metal to check the flame an explosion followed. Turning to the electric bells as used at Senghenydd and many other collieries, the author has suggested the proper criterion as regards sparking. On page 421 he gives the inductance of those bells. It will be seen that bell No. 1 has an inductance of something over 0·5 henry, and the oscillograms given on page 423 show that the current was about 0·4 ampere at the moment of breaking. That means that the electromagnetic energy in the bell when the circuit is closed is something of the order of 0·04 joule, which represents the energy available to create a spark. Now, is it possible by means of a condenser or any other auxiliary apparatus to suppress the spark by diverting that energy into another channel? We all know that theoretically it is possible; and speaking from experience I can say that it is practically possible to suppress a spark resulting from much more energy than 0·04 joule. In the Kilroy stoking indicator used in the Navy, which my firm has manufactured for the past 10 years and more, the apparatus that controls the speed at which the indicators work is a reciprocating motor or clock of a curious kind, in which the circuits of two large electromagnets are alternately made and broken. The great problem before us when we first designed this apparatus was how to break those circuits sparklessly, because the instruments had to be shut up in a case, sealed, placed on board ship, and left to work for many years without any attention. The electromagnetic energy of those magnets, together with that of the indicators in series, varies from about 1·2 joules up to 2 or 3 joules, or from 30 to 60 times the energy in the Senghenydd bell, yet with this apparatus, even after working for seven or eight years without any attention whatever and making and breaking the circuit several million times, it is quite impossible to see any spark on breaking the circuit, and it should be noted by those who see danger in 9 or 10 volts that the Kilroy stoking indicator is run from the ship's mains at 100 or 200 volts. That is an example of what can be done by means of a condenser properly applied to suppress sparking. But in that case the circuit is made and broken at intervals of possibly a minute or more, and under those conditions it is comparatively easy to devise a condenser system which will suppress the spark. The problem is by no means so simple when we come to a trembling bell, but it is one which any young electrical engineer—a modern man who knows all about oscillographs, induction, and energy—would find it worth while to take up, because it is quite capable of being solved. When we can produce a bell in which there is absolutely no visible sparking one half of the suspicion with which electric signalling systems in collieries are regarded will have disappeared. Now as to the other difficulty, namely the sparking when the bell circuit is closed and opened in the roadways. That is really a greater difficulty than the bell itself. It can be solved, I believe, by condensers, but it is more difficult because the conditions under which the contact is made and broken vary according to the man and according to the means by which he does it. I said just now that I discriminate between the spark (the incandescent air which is carrying the current) and the flash which is produced by vaporizing the electrodes. If we are wise we use pure platinum or iridio-platinum for electric-bell contacts and take care that absolutely no other metal comes anywhere near the spark-gap, so that there is nothing whatever to vaporize. But for the circuit wires, practically the worst kind of conductor is used, namely, zinc on steel or iron. We all know what happens when we break an inductive circuit between two iron wires: we get a flash, and zinc only adds to the flash. It is worth considering whether as an additional safeguard it would not be worth while putting in copper wires instead of galvanized iron or steel. It is quite true that copper wires are very much weaker, but it is possible to get steel wires coated with copper which would work equally well. I do not say that copper cannot be vaporized, but there is far less flash from copper than from iron. I have indicated now what I believe to be the directions in which we must work in order to make this simple system of signalling, which is so well adapted for colliery working, not only perfectly safe but absolutely free from suspicion. By adding to the perfection of all the machinery of a colliery, electrical engineers are necessarily making colliery working less dangerous; but do what we will it cannot be made a perfectly safe business and we must all realize—everyone does realize it who has anything to do with colliery work—where the main point of danger lies. It lies in human nature, and so long as human nature is what it is, and a collier's nature is what it is, there will be danger; but that danger is rapidly being reduced by the perfection of the mechanical and electrical appliances of a modern colliery.

Mr. L[arke].

Mr. W. J. LARKE: I was very pleased to notice on page 402 that the author makes a strong plea for the earthed neutral; and I trust that he will go further and endeavour to persuade the Home Office to make the earthed neutral compulsory. I have had made to me the same reply that the author states was made to him, namely, that the advantage of not earthing is that it is possible to continue working with a fault on the system. I consider that to be the very reason why we should insist on earthing. There is no reason for not earthing, now, even on the grounds of continuity of supply, because with the numerous satisfactory selective protective devices that are available it is possible to use an earthed system and still ensure that the discontinuity of supply due to a fault is limited to that section of the system in which the fault occurs. Therefore we are not justified in incurring such risk as must inevitably result from having an unearthed system with a possibility of an earth on one part which cannot be immediately detected. I was also pleased to note that the author states on page 407 that "in order to deal with further extensions some of the larger motors will probably be fitted with power-factor correctors." I venture to think that the

[illegible] motor used in this connection would be of the order of [illegible] in the rheostat referred to by the author, those losses will [illegible] we should practically save the whole of that 10 [illegible] by 20 per cent. [illegible] well be borne in [illegible] us when dealing with this problem. On page 418, under the heading "Small Surface Motors," I [illegible] surprised to note that the author preferred to [illegible] type of motor. I should have thought [illegible] element in mines [illegible] to the present [illegible] I would like to draw attention to one source of danger which the Powell [illegible]

[illegible]

Mr. [illegible]

[illegible] author refers to three sets of measurements of the resist- [illegible] know why the [illegible] that I wish to [illegible]

Mr. J. W. [illegible]

Mr. Holliday. to be that at least 25 per cent of the total resistance to earth is within a layer 1 ft. thick adjacent to the surface of the coke. The temperature of this layer gradually rises, being highest next to the coke. As the temperature rises the resistance falls, but the rate of decrease in resistance is less at a high than at a low temperature (see Fig. A herewith). As the I^2R loss and heating effect is smaller

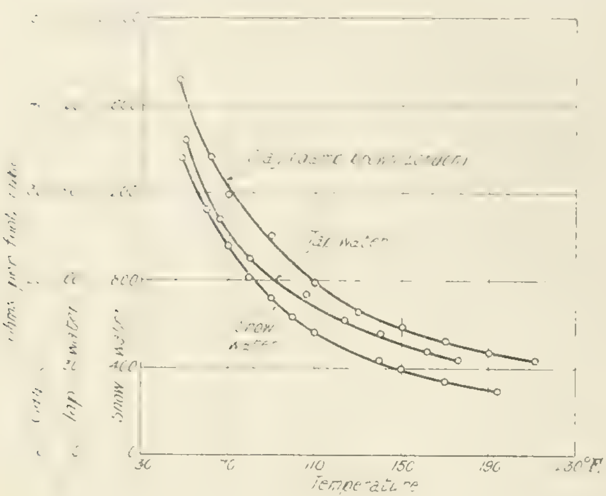


Fig. A.

as the resistance decreases, further decrease in resistance is more gradual. Tests made on samples of clay, sand, and water, show that in each case the resistance decreases with increase of temperature, the resistance-temperature curves being of the same general form. The resistance decreases approximately 50 per cent for an increase of

Material	Temp., °F.	Ohms per ft. cube	Remarks
Damp brown London clay	50	40	Average of 3 samples
Damp brown Thames sand	50	92	" 2 "
Damp yellow gravelly sand	50	220	" 1 "
Damp Thames ballast	50	610	" 1 "
Damp small shingle ...	50	1,260	" 1 "
London tap water ...	50	100	" 3 "
Snow water	50	1,350	" 2 "
Distilled water ...	50	1,500	" 2 "
+ 0·008 % common salt	50	175	Per cent by weight
+ 0·016 % "	50	90	" "
+ 0·024 % "	50	62	" "
+ 0·030 % "	50	40	" "
+ 0·054 % "	50	29	" "
+ 0·081 % "	50	20	" "
+ 1·00 % "	—	1·7*	See footnote
+ 10·0 % "	—	0·28*	"
Gas coke as used for the earth-plates Nos. 1 and 2 referred to in paper	50	0·06	Under pressure of 1 lb. per sq. in.

* From Whittaker's "Electrical engineers' pocket book, 1906," pp. 88 and 182 (authority, Kohlrausch).

temperature from 50° F. to 100° F., and approximately 75 per cent for an increase of temperature from 50° F. to 200° F. Some tests were carried out to ascertain the resistance of various materials when passing alternating current, 50 periods. The results are given in the preceding table. Mr. Holliday.

The principal factor in the resistance of the various soils tested appears to be not so much the percentage of water as the presence of traces of soluble salts which lower the resistance enormously. When all the water is driven from any soil tested it becomes practically an insulator. From the tests made it appears possible to allow certain alternating 50-period current densities at the surface of coke earth-plates buried 8 feet from the surface in clay, depending on the time the current is passing.

(1) For short periods up to 5 minutes—25 amps. per sq. ft.
(2) For longer periods up to 3 hours—6 amps. per sq. ft.
(3) Continuously—0·75 amp. per sq. ft.

With less favourable conditions in gravel or other soil the figures would have to be materially reduced. In carrying out the tests it was found difficult to obtain an independent earth as a datum line from which to measure the potentials on the plates. An earth connection was made at a point some three miles away, and an insulated cable brought to the point where the tests were carried out, so as to eliminate the effect of the charging-up of metal-work in the vicinity due to stray currents.

Mr. A. Rushton: There are just two points that I want to mention. One is with regard to electric winding. So far as can be judged from figures that are published, electric winding does not show any great advantage as regards steam consumption compared with high-class steam winders; and any advantage electric winding seemed to have over steam winders has been considerably affected by the advent of the exhaust-steam turbine. So that if electric winding is to have the success that it should have, it will only be by using the cheapest and simplest method of winding, coupled with the supply of cheap power. This, in my opinion, necessitates bulk supply to collieries from large generating stations in mining districts. The generating stations may belong to the colliery owners themselves. If this is done, it is possible to use induction-motor winders, and where there are a large number of induction motors the peaks of the several winders will be eliminated, and the load variation would not be felt very seriously on the power station. Even where the generator capacity is limited and there are two winders, one for each shaft, it is quite possible to do something in this direction by arranging the acceleration of one winder to coincide with the retardation of the other. It seems to me that the problem of electric winding would be much better tackled on the above lines than by each colliery company building its own generating stations and thereby practically forcing itself to the expense of equalizing the winding load, because this forms such a large proportion of the total demand. I think it can hardly be gainsaid that equalizing is very expensive. In this case, taking the Britannia winders, machines having a total capacity of about 7,150 horse-power are necessary in order to cope with the load, which averages about 2,600 horse-power, that is, just sufficient load for one set, Mr. Rushton.

[illegible] It is true that the [illegible] practice. To have the [illegible] is therefore very satisfactory, and renders it unnecessary [illegible] of tramway cases shows that the [illegible] plates not less than 20 yards apart rarely results in such a [illegible] possible." Numerous experiments show that it is of little use to make the plates larger than 4 ft. square, giving a total [illegible] fall appreciably with an increase above that amount. Nor [illegible] seem to make an appreciable difference whether [illegible] are buried in a vertical or a horizontal plane, [illegible] when the vertical [illegible] gives the lowest [illegible] hydrogen polarization, but that does not happen; probably the osmosis effect and the presence of salt solutions ensure [illegible] the earth connection for the neutral should be, as the

[illegible]

[illegible] commercial [illegible] units and [illegible] is the great obstacle to complete [illegible]. The author's account of the electrical [illegible] outfit [illegible] gear. [illegible] is probably not the most important point. The capital [illegible] It is [illegible] needed would be much more mo[illegible]

and colliery owners to turn their attention to this line of advance.

Mr. [illegible] F. DRIVER (*communicated*): In collieries and similar undertakings in which large amounts of power have to be transmitted for, comparatively speaking, short distances or distances which prohibit the economic employment of very high voltages, the section of the conductors is quite large, and consequently their cost forms a very large percentage of the total cost of the complete line. This has already been conclusively proved by such schemes as those of the Weardale Steel, Iron, and Coal Company, the Ebbw Vale Steel, Iron, and Coal Company, and Messrs. Newton, Chambers & Co., where the section of the conductors varies from about ¼ to 1½ square inches of aluminium, and in which the overall economy realized by employing aluminium was in the neighbourhood of 20 per cent. If aluminium conductors had been used for the wood-pole transmission lines in the present instance, I estimate that a saving of something like £2,000 could have been effected, less about £400 due to the increase in cost of the poles, or a net saving of about 15 per cent on the complete scheme. The steel-pole line now under construction does not offer perhaps so much inducement to utilize aluminium, owing to the very small size of conductor, 0·073 square inch, the aluminium equivalent of which would be 0·122 square inch. With this section the difference in deflection would necessitate taller supporting structures in the case of aluminium, so that the extra cost of poles would probably exceed the saving on the conductors. Nevertheless it has been my experience that in nearly every case in which the size of aluminium conductors exceeds about 0·1 square inch the overall cost of the line is considerably less than that of the corresponding copper line.

Mr. L. B. ATKINSON (*communicated*): This paper affords an illuminating summary of the present position of electrical power distribution for colliery purposes, and indicates by the growth of the Powell Duffryn installation in the period since the author's previous paper of 1905, that the application of electricity to coal-mining has overcome its earlier difficulties and become an assured economic success. As a very early worker in this field I well realize the nature of the difficulties that have been overcome, but one of the greatest was overcome by the author when he became associated with the Powell Duffryn Steam Coal Company and with their General Manager, Mr. E. M. Hann. The paper is full of points of great technical interest, but I only propose to mention one or two. The question of electrically-driven main winding engines is of course a very hotly debated one, and some authorities are definitely of opinion that it is economically unsound to use them, but taking a broad view, the amount of power used in winding being, as it is, a large percentage of the whole power used, has an important bearing on the total output and therefore economy of generation of the whole supply, whether this be done at the colliery or at a power company's works. When one comes, however, to the realization of main winding by the use of Ilgner sets I think that most colliery engineers will look upon it as a *tour de force* not tempting imitation. The adoption of this system at the Powell Duffryn Colliery is explained by the necessity of overcoming the peak loads, but this reason should not apply on a system aggregating 24,000 kilowatts except from the point of view that this total is not really interconnected into a single generating unit. So far as winding is concerned it will not become generally adopted if Ilgner sets have to be used, and one of the lessons to be learnt appears to me to be this. The equipping of collieries even on the scale of the Powell Duffryn as generators of electricity should be done in conjunction with a power company's supply. It is true that by generating power at the colliery, waste coal and gas can be used, and in this case apparently 35·5 million units out of 50 million units are so generated, but the separate generating units, steam, gas, etc., should feed into the power company's mains from which the supply required would be taken, and thus considerable saving on spare plant and peak-preventing devices would be effected. It is unfortunate that South Wales, which would have been one of the most favourable areas in the world for a power company merging and supplementing the sources of waste power and heat from its collieries and iron and steel works, has from a variety of circumstances, mostly unconnected with engineering, missed its great opportunity. It is interesting and suggestive to find so considerable a part of the paper devoted to the question of bell signalling. Whether the disastrous Senghenydd explosion was caused by a sparking bell or not, there is no real difficulty in producing a bell in which, by the use of a non-inductive resistance or condenser, either no spark is produced, or in which the spark is enclosed in such a way as to be innocuous. As the author points out, however, in his paper, the greatest danger is, after all, probably due to sparks on the bare iron wires used, and between which contact is made. There is no reason why this sparking should not be considerably diminished. First, if the wires were of copper the self-induction would be less, hence the energy to be dissipated would be less; second, they might well be connected at intervals to some form of cheap electrolytic condenser; and, further, if relay bells were adopted the currents might be reduced to amounts which would not produce a spark capable of firing gas. So that really this question resolves itself into recognizing the danger, and in laying down in the colliery rules certain limits of energy in the lines as defined by their electrical constants and the voltage applied.

Mr. C. P. SPARKS (*in reply*): My thanks are due to all members for the way in which this paper has been received, and my special thanks are due to Mr. Merz for his generous criticism. One point touched on during the discussion, namely, that the whole of the work has been carried out without Parliamentary powers, is not connected with the subject-matter of the paper, but it has been an important factor in the rapid development of the electric system, as, had the interconnection of the various collieries depended upon Parliamentary powers, the scheme would never have assumed its present magnitude. At the same time it will be noted that all work has been carried out to at least as high a standard as that necessary if it had been done under Parliamentary powers.

Supply of electrical energy.—Mr. Merz adds a material point under this heading. I agree as to the importance of lowering the cost of distribution and as to the saving due to the omission of stand-by plant, by collieries and power companies working together when the frequency is the same. Unfortunately, the South Wales Power Company

[illegible]

Earth [illegible]

[illegible] by an insulated cable to [illegible]

[illegible] the large number of well-bonded iron c[illegible] this distributing centre and to the nature of [illegible]

[illegible] tall [illegible] is passing [illegible] of earths artificially salted so as to lower t[illegible] it is necessary periodically to [illegible] weeks in order to maintain a [illegible] members.

[illegible] of making good earth connections bel[illegible] mines it is not possible to rely on a number of [illegible] to the operation of protective devices, and [illegible]

[illegible] but owing to the increased strain due to windage, I am not [illegible] aluminium; and having once standardized the use of copper conductors for transmission it has not been found worth while modifying the general construction when making extensions.

[illegible] obtained from live-steam stations—in fact I am obtaining better results in the Metropolis with a lower station load factor—but I felt it only fair to compare actual steam with actual gas results obtained by the same undertaking. We [illegible] results have been obtained in certain cases [illegible] I). Mr. Sayers suggests that the use of gas [illegible] I cannot agree with this expression of opinion, as it will be seen on reference to the paper that only a section of the output can be economically supplied by the gas plant, [illegible] demand so as to provide a constant load on the ga[illegible] station.

[illegible] state that the present Regulations are far in advance of

r Sparks of earths of the character of main station earths or of large contact areas.

Power-factor correction.—Mr. Larke raises an interesting point in connection with the 1,750 b.h.p. converter sets. When the enquiry was made for this plant in 1910 the questions of saving the loss in the slip regulator and of the improvement of power factor were discussed, and no contractor was able to offer any proposal. I am glad to learn that present developments make both these points practical.

Main winding.—When the Britannia winding plant was ordered in 1910 the main reason for using equalizing plant was the small size of the generating plant and the difficulty of interconnecting the various power stations. With the further interconnection of the colliery company's system by means of the 20,000-volt transmission line now in hand, which will allow plant to the amount of 24,000 kilowatts to operate in parallel, the principal necessity for the use of equalizers disappears. An additional converter set without a flywheel and of the same capacity as the existing sets is now under consideration. The set will consist of a 1,750 b.h.p. induction motor driving continuous-current generators controlling the motors on the Ward Leonard system. In answer to Mr. Merz's question, I am of opinion that with reasonable duplication of generating stations and transmission lines the cost of balancers would not be warranted in order to complete a wind.

Mr. Rushton questions the advisability of using electric winders. While it is true that no large saving in fuel consumption is attained during the main winding shift, very considerable economies result through reduced stand-by losses during the balance of working hours. It must be remembered that in South Wales coal is only wound during an 8-hour shift. I agree with his suggestion that successful electric winding can only be obtained where a supply of energy is available at low rates. From my experience such a supply can be generated by a large colliery undertaking. The cost of electric energy for winding from the full depth of 730 yards when the colliery is developed will be under 1d. per ton of coal wound.

With reference to the further point raised by Mr. Rushton, I think the colliery management would not tolerate interference with working, such as would be necessary if winders were timed so as not to synchronize. The continuous input into the induction motors with two main winders working at full duty would be about 3,600 b.h.p., while the momentary maximum demand of the winding motors when the two winders synchronize would be 8,600 b.h.p.

The total power plant of the Powell Duffryn Company aggregates 74,000 horse-power, of which some 30,000 horse-power still consists of steam winders, compressors, and a few fans. As these plants require replacement, I am of opinion that a considerable portion of these drives will be electrified.

Mr. Sayers suggests the use of a continuous winder. This has been an ideal for many years, but it has not been found practicable to put it into operation, even on a small scale. Any system of continuous winding necessitates Mr. Sparks emptying the trams below ground into a conveyer, and anyone conversant with colliery practice will recognize the difficulty of finding space to handle and screen coal below ground. Unless this were done it would interfere with the present basis of contract between the employers and workmen for checking the coal output. This point is fundamental, and any departure would result in endless trouble with the Trade Unions.

Haulage.—Mr. Merz draws attention to Fig. 27. This is a draughtsman's error. The high-speed gear should have been shown double helical as in the case of Fig. 26.

Lighting.—Mr. Larke draws attention to Mr. Ralph's electrical recorder of the percentage of pit gas present. While the instrument has ample range and is no doubt of great value, in my opinion it is still necessary to have a percentage of safety oil-lamps, as in many instances the only warning of the presence of gas is by a lamp going out. For the electric indicator to be effective it would either have to give an audible signal or suddenly to change its illuminating power so that the miner's attention might at once be directed to the indicator.

Electric signalling.—I am in agreement with practically everything that Mr. Evershed has said, and I am very glad to have his support in what he said about the suspicion attached to the electric bell. While the electric bell was suspected it was in evidence that a lamp re-lighting station existed in the mine where, under an old Government regulation, a naked flame was allowed. We all know that the naked flame was a very dangerous thing, and to cover this point we have had the electric-bell theory exploited. Mr. Evershed gives a clear definition of the principal factor making for safety or danger in signalling, being the electromagnetic energy stored in the circuit to be broken. When dealing with this point on page 422 of the paper I refer to the necessity of considering the inductance of any circuit before specifying the safety limits in terms of volts and amperes.

With regard to the suggestions for protection, Dr. Thornton's experiments show that a bell contact can be rendered perfectly safe by shunting the bell coils through a high resistance. This appears to be a simple and effective way of dealing with the less dangerous factor in the signalling circuit. With regard to the open wires, while Mr. Evershed's suggestion of coppered iron in place of galvanized iron is of value, I consider it to be undesirable to continue signalling by making contacts between the bare wires themselves in the presence of gas, and I strongly favour the use of enclosed switches to complete the circuit, the switches being controlled by pull wires.

With reference to the point raised by Mr. Cooper as to Fig. 30, these results are plotted so as to show the difference in the characteristics of the bells actually in use at Senghenydd and those tested by the Home Office as "a Senghenydd bell." I agree that the pressure might have been measured across the bell terminals, but this would not have resulted in comparative figures, as the pressure across the bell terminals was not given in Dr. Wheeler's report.

POLYPHASE COMMUTATOR MACHINES AND THEIR APPLICATION.

By V. Shuttleworth, M.Sc., Associate Member.

[illegible]

[illegible] they can accomplish a given object more cheaply than it [illegible] machines and converting plant.

[illegible] been omitted. The possibilities and potentialities of the [illegible] discussed from time to time and are well known.

[illegible] 3-phase machine, and it will be understood that the principles involved apply to any other number of phases.

It will expedite matters first of all to enumerate the fundamental qualities possessed by an armature fitted with a commutator connected in series with a stator compensating winding in the presence of a rotating field. For 3-phase current the brush spacing on a commutator is naturally 120 electrical degrees. The closed circuit winding of the armature, so far as 3-phase currents passing in and out at the brushes are concerned, is equivalent to a delta-connected winding. The three separate phases of a compensating winding are placed in series with three brushes respectively, and they are distributed on the stator in such a manner that the currents passing through them neutralize the armature currents at all points along the periphery. Let it be now supposed that the delta armature-winding is replaced by an equivalent star-connected winding terminating in the brushes; it would be found that the three phases on the armature possess exactly the same number of turns as the compensating winding, and that they are wound immediately beneath [illegible]

[illegible] the true windings represented in Fig. 1, the equivalent [illegible] considered separately, and it is sufficient to remember that [illegible]

[illegible]

Fig. 1.

[illegible] the result that there can be no voltage between the

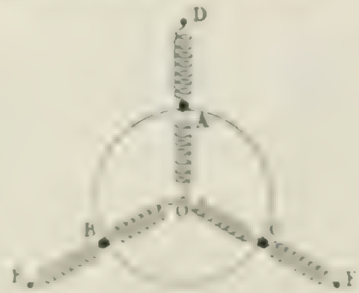


Fig. 2.

terminal D and the star point O. These relations are shown in the voltage diagram, Fig. 3, from which it will be seen there can be no voltage between the terminals of

Fig. 3.

Fig. 4.

[illegible] The [illegible] upon the [illegible]

If it now be assumed that the armature rotates slowly in the same direction as the rotating field, the relative velocity of the field to the armature has decreased, and the voltage induced in the armature must decrease also ; no change can have taken place in the frequency of the voltage at the brushes, or in the magnitude of the voltage induced in the compensating winding, and the result will accordingly be as shown in the vector diagram, Fig. 4, where A B C is the armature voltage, and D E F the terminal voltage.

Proceeding further, examine the result when the speed of the armature attains to that of the rotating field, namely, synchronism. The field has now no motion relative to the armature conductors, hence there can be no voltage induced in the armature, and the voltage in the compensating winding remains the same as in the previous cases ; the results represented by Fig. 5 are then obtained.

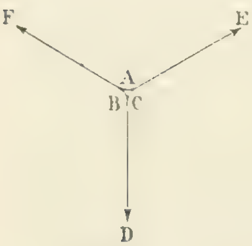


FIG. 5.

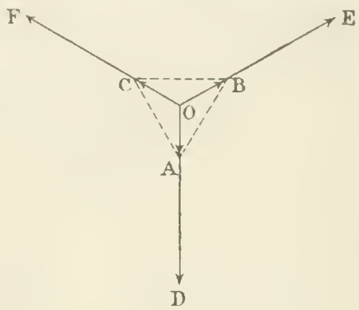


FIG. 6.

The only remaining case is that of an armature speed higher than that of the rotating field ; the direction of cutting of the field by the armature conductors becomes reversed, and the phase of the voltage generated at the armature brushes is of opposite sense to the previous cases. Fig. 6 depicts the armature and terminal voltages under this condition.

There are two observations to make from Figs. 3 to 6 ; one is that there is a different ratio of armature voltage to terminal voltage at every speed, and the other that the terminal voltage is exactly the same as regards magnitude as it would have been with a stationary field.

The rotating field determines two things ; first, the seat of the voltage, namely whether it appears in the stator or the rotor ; and second, the frequency of the voltage appearing at the armature and terminals of the machine.

With these simple facts in mind the mode of operation of all commutator machines will become more clear.

Broadly speaking, there are two main types, classified according to the method of excitation, namely :—

(1) Shunt.
(2) Series.

The former implies constant field, which is usually associated with constant speed under load, and the latter with compound excitation with varying speed under load.

Machines of the shunt type will be considered first.

It is evident that a single-speed commutator motor is practically useless ; the only advantage over an induction motor is an improved power factor, but this is not sufficient to merit the increase in cost. The real advantage of a commutator machine is the possibility of speed variation, which can be accomplished without loss of efficiency. A variable-speed polyphase shunt commutator motor is the prototype of the continuous-current variable-speed shunt motor. The many speeds are obtainable by simple regulation of the field excitation.

LATOUR MOTOR.

The first motor to be considered is one built to the design of M. Latour in France. The published information being very meagre it will be supplemented by showing the necessities for successful operation in a motor of this kind.

Fig. 7 is reproduced from a paper presented by R. Legouez at the Turin Congress.*

The motor proper is fitted with a 3-phase compensating winding (1), and a 3-phase armature (2). Instead of using a separate shunt exciting winding the armature winding is used for this purpose, and an exciting voltage is impressed between the brush studs from the secondary (3) of a transformer, the primary of which (4) is connected to

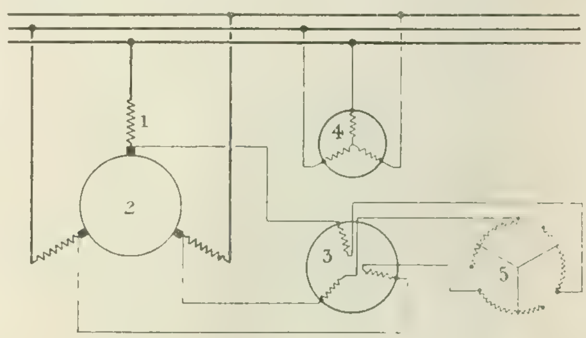


FIG. 7.

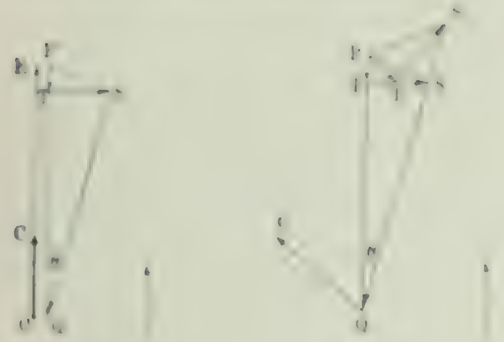
the supply system. The armature winding of the motor therefore carries in addition to the load current an exciting current, which produces the working field of the motor. The windings of the transformer (3) carry only a wattless current, which is at right angles in phase to the voltage induced from the primary. The latter fact enables a very simple means to be employed for varying the terminal voltage of the secondary of the exciting transformer, and for this purpose the star point of the secondary is completed through a variable reactance (5). A voltage-drop due to the magnetizing current flowing through the reactance (5) is exactly opposite in phase to the voltage induced in the secondary of the transformer ; since the voltage appearing in the windings (3) is constant under all conditions, the terminal voltage impressed on the brushes of the motor will depend upon the magnitude of the voltage-drop in the reactance, and the reactance is therefore a means of varying the impressed voltage on the field winding of the motor—this being done also without any change in phase. It will be observed that the reactance (5) is strictly analogous to the field rheostat of a continuous-current shunt motor.

For reasons which will shortly be apparent, the transformer (3–4) must be made with a movable secondary,

* R. LEGOUEZ. Moteurs polyphasés à collecteur. Congresso Internazionale delle Applicazioni Electriche, Torino, September 1911.

[illegible] the primary [illegible]

[illegible]



[illegible]

rotation.

[illegible]

flux.

[illegible] exciting voltage. It is determined by the phase of the exciting voltage derived from the secondary (3) of the [illegible] as previously intimated may be regu- [illegible]

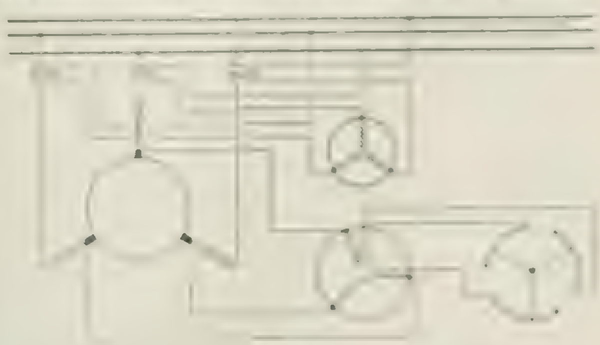
[illegible] drop, P T, at all times indicating the phase of the load current. At some other load the impedance triangle takes up some position such as P T_1 S_1, as shown in Fig. 9, the current vector Q C being parallel to P T_1; the counter electromotive force of the machine has [illegible]

[illegible] wattless and the vector [illegible]

[illegible]

compared with the reactance pressure-drop, but the speed variation between no load and full load will still be large.

[illegible] with the load current. [illegible] factor under all loads, and [illegible]



[illegible] the actual machine it is impossible to say, but from the success that he claims it would seem probable.

[illegible] is shown. A small reactance is fitted in series with each [illegible] is connected in series with [illegible] exciting transformer, then each [illegible]

of the exciting transformer receives a voltage which is tilted in phase relative to the true star voltage of the supply system. The angle of tilt depends on the value of the voltage derived from the secondary of the small added reactance, which is proportional to the load current, and may be made equal to the desired angle θ at a given load current. This automatic tilting of the phase angle in the primary of the exciting transformer is transmitted to the secondary, and hence to the exciting voltage of the motor and its field flux.

It is not possible to give characteristic curves of a machine designed on these principles. So far as the author is aware none have been published. Fig. 7, given by Legouez, is suggestive of being intended to illustrate the principle only, and not the actual system of connection. It is extremely unlikely, for instance, that the exciting voltage is impressed on the armature, as this requires increased brush-gear and commutator to carry the exciting current, which seems quite unnecessary. It would be much cheaper to use a separate exciting winding on the stator of the machine.

There is a difficulty in designing a simple armature and compensating winding for normal voltages except with very few poles, and it will be generally necessary to provide a transformer for the whole of the power in order to obtain a voltage suitable for the motor.

Whatever the methods employed by M. Latour, to obtain a successful motor on these principles, especially for a frequency as high as 50 cycles, it is quite certain that there is considerable auxiliary apparatus in addition to the motor itself, and this tends to make the equipment very costly. However, machines of this type are stated to be in commercial operation, and in order to be able to compare them with other types it is necessary to trespass outside the scope of this paper, and consider the machines from the standpoint of commutation.

The following table has been compiled from this point of view, and the last column gives the permissible percentage speed variation above and below synchronism for motors supplied from a 50-cycle circuit.

TABLE I.

50-cycle Motors.

Horse-power	Number of Poles	Speed Variation above and below Synchronism
		Per cent
25	6	50
50	8	40
100	8	30
200	10	23
400	12	18
500	12	10

For small sizes the speed range is considerable, and becomes greater the smaller the machine. For large sizes the speed range is very limited, and is not sufficient for the usual practical requirements.

EICHBERG 3-PHASE SHUNT COMMUTATOR MOTOR.

Another example of a variable-speed motor with shunt characteristics is the Eichberg 3-phase commutator motor. The original motor is represented by Fig. 13. The motor is simply an armature fitted with a compensating winding, and exciting voltages are impressed from the auxiliary auto-transformer, which is permanently connected in star to the supply system, and is provided with tappings, each of which may in turn be connected to the brushes of the motor. It will be observed that by varying the ratio of the two arms in each phase of the auto-transformer there is a different ratio between the armature and compensating-winding voltages on the motor, and this, as previously seen, implies variable armature speed.

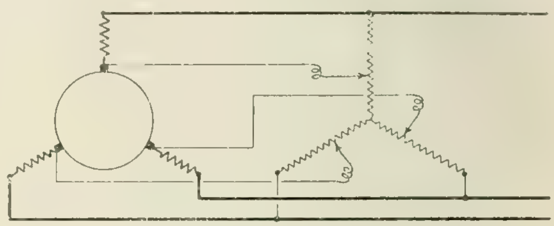


FIG. 13.

The very fact that the armature and compensating winding have an equal number of turns and are wound in opposite directions prevents energy being transferred from stator to rotor, or vice versa, by induction. An auto-transformer connected in parallel cannot therefore act as a power transformer, and it carries only the wattless exciting current required by the motor. Speed regulation by the means described is a comparatively simple matter.

Unfortunately, if good operation is to be maintained, this simple motor cannot be constructed with a sufficiently large number of turns in the armature to suit normal supply voltages. It is quite imperative in practical machines that the number of armature turns be considerably reduced. This being so, the auto-transformer at once becomes a power transformer, and delivers a portion of the total input of the motor direct to its armature at comparatively low voltage and heavy current. The effect of the change is considerably to increase the capacity of the transformer, and it entails also a massive controller to deal with the heavy currents between the transformer and the brush-gear.

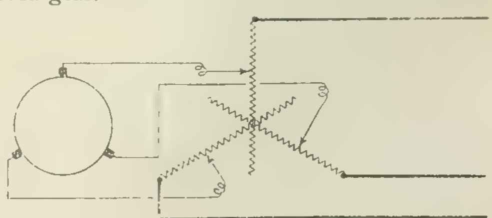


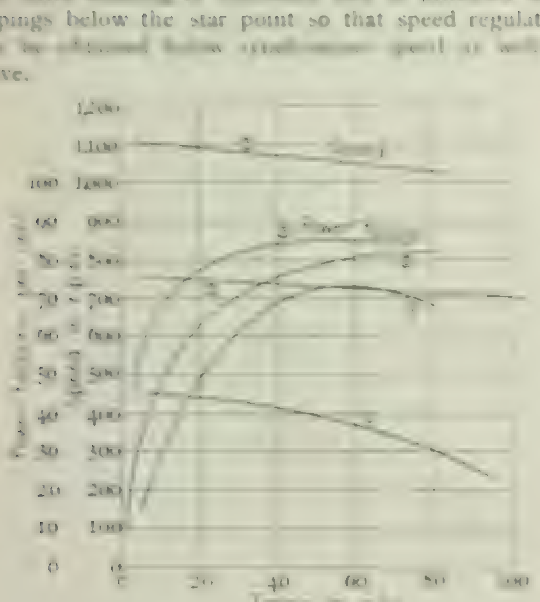
FIG. 14.

The necessity for a transformer, however, vanishes when the stator and rotor turns are no longer equal, as it becomes possible for power to pass from stator to rotor by induction, and the functions of a transformer may be embodied directly in the motor in addition to its previous duties. The modified machine is shown in Fig. 14, where

[illegible]

[illegible]

tappings below the star point so that speed regulation [illegible] above.



The possible speed variation with this type of motor [illegible] It is very doubtful if a 200-h.p. machine could be built [illegible]

[illegible] the stator is exactly similar to that of an ordinary in- [illegible] wise fitted with a [illegible] directly in series with the armature, to introduce a trans- [illegible] tension system.

[illegible] other speed than that at which [illegible] very [illegible] inductive drop. The alternating-current motor possesses the advantage that without series resistance it [illegible]

direct on to the supply system without the introduction of any starting devices. Any initial torque such as is required to start the load may be obtained by moving the brushes from the position of rest, and, in general, full-load torque is exerted with half full-load current, and other torques in proportion. It will have been gathered from the foregoing that the motor is quite unsuited for maintaining a constant speed under a variable load torque, unless the changes are very gradual and allow of a change in the brush position in the meantime, but for loads with torques which remain practically constant at all speeds, or torques which vary only with the speed, the motor is eminently suited.

Centrifugal pumps, blowers, and ventilating fans, and also reciprocating pumps and Root's blowers may be cited as examples. The torque varies approximately as the square of the speed in the first three drives, and for the others is

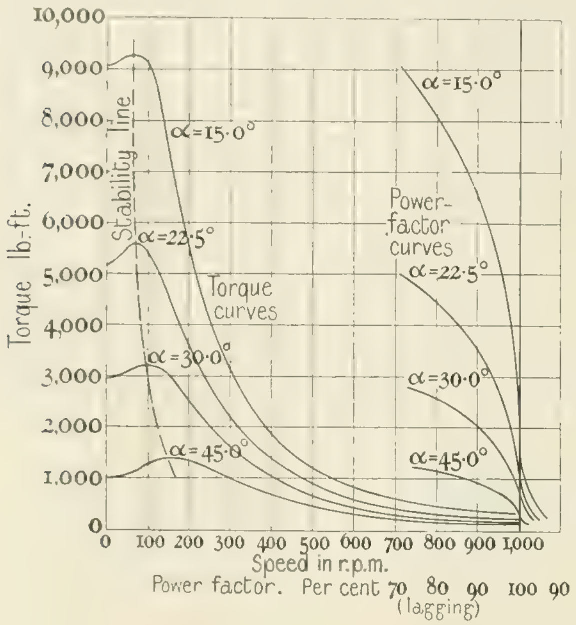


FIG. 17.

practically constant over a wide range of speed. In the former cases the series commutator motor is capable of producing speed variation from standstill to the maximum value in a perfectly smooth and gradual manner. It is not usual, however, to make provision for working at very low speeds, because the output falls off so very rapidly, and is less than is required in practice.

The speed-torque characteristic of the motor possesses a certain peculiarity at low speeds which prevents a large torque such as full-load torque being maintained in a stable manner below a speed which is approximately one-third of the maximum value, and this has an important bearing on constant-torque drives. Instead of the inherent torque of the motor commencing to fall immediately the armature has started from rest, it gradually rises to a certain maximum which is slightly higher than the starting torque; then it begins to fall away in the usual manner as the speed increases further; consequently if the motor starts against a load torque which remains constant, the inherent rise in the motor torque causes acceleration, which continues until the torque falls again to a value equal to that required by the load.

The speed-torque curves given in Fig. 17 are those of a 100-h.p. 25-cycle 8-pole motor. The brush shift from the short-circuit position is marked in degrees on each curve, and the dotted line drawn through the points of maximum torque may be termed the stability line, because any torque point on that line shows the minimum speed at which that torque can be maintained. Suppose, for instance, that 375 r.p.m. is the full-load speed of the motor; the full-load torque = 1,400 lb.-ft., and to get this torque at low speed the brush angle, α, must be slightly less than 45°; the motor would exert this torque at 140 r.p.m. approximately. For small brush angles the motor accelerates, so that when $\alpha = 30°$ the speed becomes 335 r.p.m. and at $\alpha = 23°$ the speed is 375 r.p.m. Stable operation under full-load torque cannot be obtained at a speed less than 140 r.p.m.; starting torques greater than full load may be obtained, but the armature would continue to accelerate to speeds above 140 r.p.m. The stability line, therefore, has special impor-

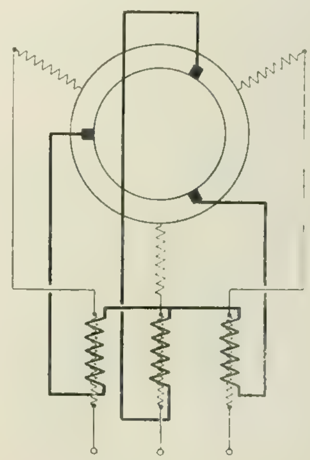


FIG. 18.

tance in showing the speed variation of which the motor is capable at any torque, and the limiting speed before coming to a standstill.

Generally speaking, a speed range of 3 : 1 under constant torque is the utmost limit for a series commutator motor. The power-factor curves corresponding to the torque curves are given alongside, and from these the characteristics of the motor for any type of drive may be deduced.

It has been previously stated that in a machine with stator and armature turns in series and approximately equal, satisfactory design is not possible at high frequencies except for very low speeds. For all supply pressures above 200 volts it becomes necessary to interpose a transformer between the stator and rotor so as to reduce the armature voltage, but the capacity of the transformer is a fraction only of the capacity of the motor, and does not therefore add very seriously to the cost. Fig. 18 shows diagrammatically the arrangement which is employed.

Other applications to which this motor may be put are the driving of calendering machines and calico printing-presses. To a certain extent series motors are used for cranes and hoists, but as those required are usually of

[illegible] expensive. The upper limit of capacity of 50-cycle [illegible]

[illegible] efficiency at all speeds, and the good [illegible]

[illegible] Commutator Motors.

[illegible] capable of working satisfactorily over a wide range of [illegible]

It might not seem evident that an induction motor which receives energy at 40 or 50 cycles per second in its [illegible] and which depends on the speed of the motor. It is [illegible]

[illegible] the induction motor, which is purposely kept small in normal designs, there is a fixed period of time between [illegible] the corresponding phase of the impressed voltage on that [illegible] supplied with voltages of corresponding relations in time, it follows that there is a fixed angular relation in space [illegible]

[illegible] frequency until at synchronous speed both the voltage and the frequency have decreased to zero. It will be [illegible] to mechanical work and is utilized at the shaft of the main motor.

[illegible] connection.

[illegible] Motor with [illegible]

[illegible] influence on the main motor will be considered first of all.

A commutator motor of this type embodies a compensating winding in series with the armature, and a [illegible] representation is shown in Fig. 10.

[illegible]

E_1 = exciting voltage impressed on shunt field per phase.

T = number of turns in exciting winding per phase.

[illegible]

[illegible] cuit :—

[illegible]

Also for the generated voltage in the armature circuit the following :—

$$E = C\,\Phi\,Z\,n\,\frac{p}{a},\ \text{where } C \text{ is constant ;}$$

or $\quad E = C_1\,\Phi$, since Z, n, p, and a are all constants.

Since, however, E_e is a known fraction of E, $E_e = K\,E$, where K is known, and may be varied at will ;

hence $\quad E_e = K\,E = K\,C_1\,\Phi = K_2\,f\,\Phi$,

whence $f = K\,C_1 / K_2$ and is independent of Φ.

In other words for any definite value of K, the frequency must be constant, or for any one ratio of the exciting voltage to the terminal voltage there is one frequency only at which the machine will operate. This frequency may be altered conveniently by varying the ratio of the exciting voltage to the terminal voltage, and whatever the terminal voltage these relations hold good. By connecting such a machine in cascade with an induction motor, the slip-ring voltage as determined by the design of the motor is taken up by the shunt commutator motor, and the latter enforces a slip frequency only, according to the setting of its excitation.

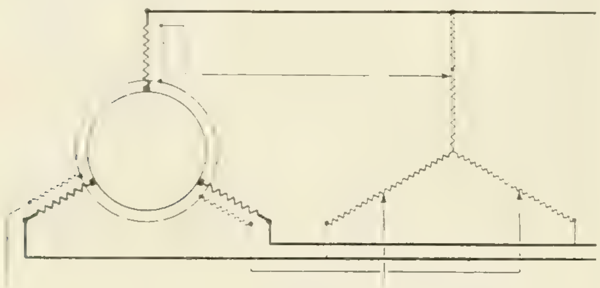


FIG. 19.

It will be evident that it becomes possible with an arrangement of this kind by varying the excitation of the commutator motor to impose a wide range of frequencies on the external circuit, which is the secondary of the induction motor, and, as previously shown, each frequency corresponds to a definite speed of the induction motor. Speed regulation becomes, therefore, almost as simple as with continuous-current machines.

The speed of the induction motor would remain constant under load were it not for the losses, which cause certain voltages to differ slightly from those at no load. Actually there is a slight extra slip produced as the load on the motor is increased, in a similar manner to the small slip which occurs when the motor operates alone with short-circuited secondary.

The capacity of the commutator motor is determined very simply as follows :—

Assume the induction motor at standstill with full-load primary input ; then, neglecting losses,

Primary volts per phase × primary amperes per phase × power factor = secondary standstill volts per phase × secondary amperes per phase × power factor.

The commutator motor has to deal with the full secondary current, and a voltage which is fixed by the maximum slip frequency employed ; thus if the lowest speed desired is x per cent below synchronous speed, the slip frequency in the secondary is x per cent of the primary frequency, and the secondary slip voltage $= x$ per cent of the standstill voltage, from which the commutator motor capacity $= x$ per cent × secondary volts per phase × secondary amperes per phase × power factor.

A cascade motor, therefore, capable of producing x per cent slip in the main induction motor must be designed for x per cent of the latter's ratings.

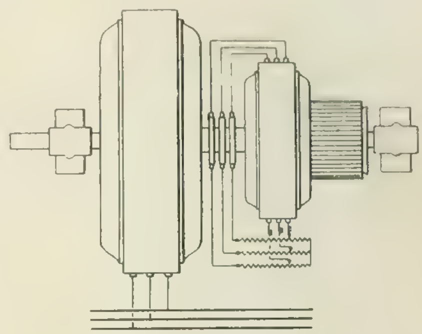


FIG. 20.

It should be pointed out perhaps that it is not essential for the speed of the commutator motor to remain constant. If it be allowed to vary, a change in the stable frequency takes place for the same setting of the excitation. In other respects the conditions are similar to those just described.

Two methods of utilizing the torque exerted by the commutator motor are in practical use. One suggested by Krämer is to couple the shaft of the commutator motor direct to that of the main motor ; this is very effective and simple provided the speed is moderately high. A low-speed motor requires an unnecessarily expensive commutator motor, and in such a case a cheaper arrangement

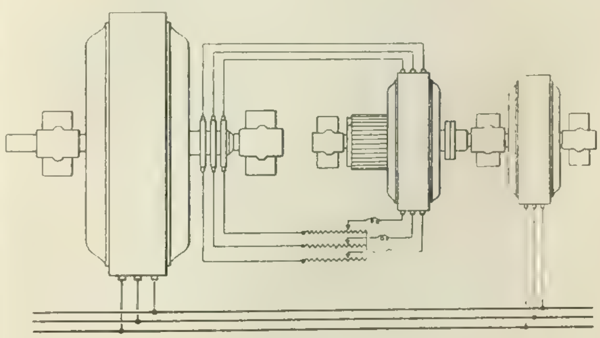


FIG. 21.

may be obtained by driving the auxiliary by a belt or by utilizing one of the many forms of enclosed reduction gearing and a high-speed commutator motor. This combination is illustrated in Fig. 20.

The other method is well known, and is due to Dr. Scherbius. The commutator motor is direct coupled to a squirrel-cage induction generator, which in turn is electrically connected to the supply system. Electrical energy given to the commutator motor at variable frequency is

[illegible]

[illegible]

induced in X O. The only counter-[illegible] oppose the impressed voltage O A is one generated by rotation of the armature in the flux due to O C. In the [illegible] voltage.

[illegible] may be split up into two components, O D and D A, one of which, O D, opposes the [illegible] and will be absorbed by setting up a current O E, the impedance pressure-drop of which opposes D A. The current circulating in this way must necessarily be a wattless current otherwise the torque produced in the [illegible]

[illegible] by making ψ negative; [illegible]

[illegible]

[illegible] and current vectors are increased five-fold. It would be [illegible] evident that the angle ψ must decrease automatically as the [illegible]

Fortunately in practice this becomes a very simple matter [illegible] been done the table on page 44[illegible] motor.

[illegible] the main motor, and without any a[illegible]

TABLE 2.

[illegible]	Slip [illegible]	Amperes per Phase	Kilowatts I	Kilowatts II	Speed of Main Motor. r.p.m.
[illegible]	0	–	–		400
[illegible]	3·5	83	3·2	−3·4	305
102	5·1	86	4·3	−4·5	340
124	6·0	98	5·9	−6·4	340
144	7·0	100	6·0	−7·2	330
[illegible]	8·1	100	8·1	−8·5	310
[illegible]	9·3	100	9·2	−9·7	307
[illegible]	10·3	100	10·2	−10·7	207

The vector diagram for load conditions may be deduced from the no-load diagram very simply. Under load there is a slight change in frequency which is associated with a corresponding increase in voltage, and proportional increase of frequency and voltage on the exciting winding of the commutator motor maintains constant flux; hence it follows that the exciting current, O C, and the generated voltage of rotation, O H, remain constant. Of the total impressed voltage, O A, one component, O D, is therefore

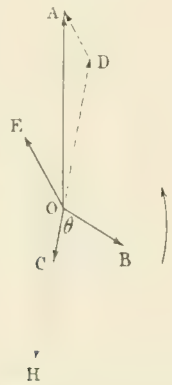


FIG. 25.

fixed, and the other component, D A, may vary in magnitude and phase according to load conditions. The current produced by the component D A is limited by the impedance of the local circuit consisting of the armature of the commutator motor and the rotor or secondary of the main induction motor. Due to the low frequency of the current the pressure-drop due to reactance is small compared with that due to resistance, and the impedance does not differ greatly from the resistance. The voltage component, D A, may vary as shown in Fig. 25 under load, and it may also be taken as a measure of the magnitude and phase of the load current. The watt component of current varies according to the torque required of the main motor, and the wattless component remains practically constant. The results are very favourable as they show the main motor to be fully magnetized from the rotor leading current at all loads, and the stator accordingly operates at unity power factor under all conditions.

The power-factor characteristic curve, I in Fig. 26, is typical of those obtained at many speeds during tests on a 500-h.p. 440-volt 40-cycle 12-pole induction motor, in conjunction with a shunt-excited commutator motor manufactured by the British Thomson-Houston Company. A few speed characteristics (curves A in Fig. 26) also bear out the conclusion arrived at from theoretical considerations.

The possibility of further improvement along these lines has been proved by following the suggestions of Milch. He proposed to employ the commutator motor as a commutator generator and to run the induction motor above synchronous speed as well as below. This introduces two problems; one is to pass through synchronism, and the second is to design a commutator machine which will not only act as a motor but will also operate as a self-excited generator at any frequency within the desired range, either on open circuit or under load. The similarity of working above and below synchronism is very marked; in one case the commutator generator delivers power to the induction motor, causing it to operate above synchronism, and in the other case power is abstracted, causing it to work below synchronism.

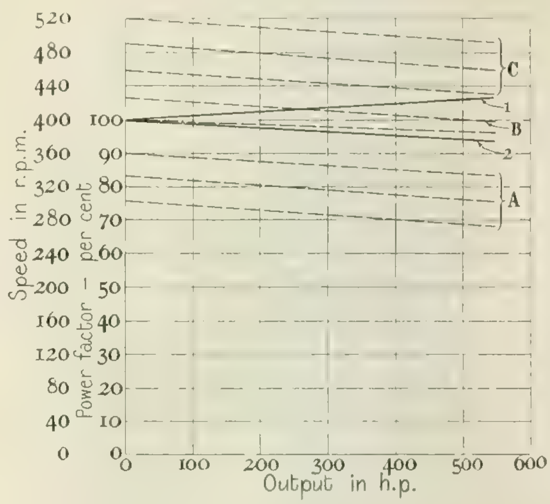


FIG. 26.

Approaching synchronism the normal tendency in an induction motor is for the slip-ring voltage and rotor current to become zero; therefore, since there is no voltage available for excitation, it is quite impossible for the commutator machine to force the passage through synchronism alone. In order to pass the synchronous point it is necessary to obtain exciting current of proper frequency and phase from a source of constant magnitude, and independent of the actual value of the frequency. This may be suitably accomplished by the use of a small frequency converter, the purpose of which is to provide exciting current for the commutator machine, separately exciting it during the period that no voltage is available at the slip-rings of the motor. The armature of such a machine is exactly like that of a small rotary converter, and revolves in a ring of laminations without windings, or the laminations may be attached to the armature and revolve with it. A voltage of supply frequency being impressed on the slip-rings, there is a similar voltage present between the stationary brushes pressing on the commutator, but the frequency of the latter voltage depends on the direction and speed of rotation of the

when there is a voltage present at the terminals of the

The vector diagram of a commutator generator is the

be mentioned here is that between the

istics obtained by the two method

synchronism at no load

would not be complete without some

problem of stability. It is well known that a

current machine depends on the saturation

necessarily be a perfect one—there are ways and means by which a series excitation may become superposed on the shunt excitation, that is, an additional excitation proportional to the armature current. So long as this excitation gives rise to a voltage which has a component opposite or at right angles in phase to the current flowing, no ill effects can result, but if it should be in the same sense as the current and of appreciable magnitude instability must necessarily occur.

The flow of current through the resistance of the armature produces a counter voltage or resistance pressure-drop, opposite in sense to the current and proportional thereto, but if at any value of current a voltage is generated in the machine greater than the I R drop and of opposite sense, there is an immediate tendency for the current to increase and become cumulative if not balanced by other means. Suppose an "active" current be present and it tends to increase from the cause just mentioned, the main motor then exerts a greater torque than is necessary for the load and the rotor commences to accelerate, bringing about a reduction in the terminal voltage and frequency of the commutator motor; but reference to the vector diagram will show that as O A decreases it entirely prevents the flow of any "active" or load current, hence the overload capacity of the commutator motor vanishes altogether.

This conclusion may perhaps be seen more directly by considering the wattless component of current. Clearly a wattless current can produce no change in voltage or frequency because it exerts no torque; and the presence of a voltage proportional to the current and in the same sense simply causes the wattless current to become cumulative, with obviously disastrous results.

The type of motor with a control system as described is only of practical service for large outputs. In small units it is much too expensive, but for large powers it becomes cheaper than a continuous-current motor and apparatus converting from alternating current to continuous current.

The limit of slip frequency is approximately 15 cycles per second, so that except for 25- and 40-cycle supply systems the amount of speed regulation is perhaps not so wide as would be desirable for some applications, and this may limit its possible field to some extent. Its use lies principally for unidirectional rolling-mill drives, and for this purpose it is admirably adapted. The speed characteristics shown in Curves A, B, and C of Fig. 26 may be made to droop to any desired extent as load is applied by the simple superposition of series excitation on the shunt excitation of the commutator machine. A considerable drop of speed between no load and full load is usually necessary for rolling-mill service in order to utilize energy stored in the flywheel.

For the driving of large ventilating fans and blowers this method of speed regulation would be superseded by the system next to be described.

Cascade-connected Series Commutator Motor.

The variability in the power factor of a brush-shifting series commutator motor at once precludes it from successful use in cascade with an induction motor, since the power factor if variable must be under perfect control for all frequencies as in a shunt commutator motor. The machine which will be discussed has fixed brush position, and if run at constant speed has a fixed power factor under all loads and frequencies. Furthermore, the system of control has been made as simple as brush shifting. Fixed brush position is necessary if satisfactory operation is to be obtained with large currents through a wide range of frequency, and the question of commutation alone is sufficient to compel its adoption in a practical machine.

The theoretical considerations differ somewhat from those hitherto discussed. The object is to compel the commutator machine to generate a voltage strictly proportional to the current passing through it and also at some predetermined phase angle to the current; this is accomplished by series excitation. In this manner, current and voltage become inseparable; *i.e.* one cannot exist without the other being present in corresponding magnitude. Secondary current, however, is essential for

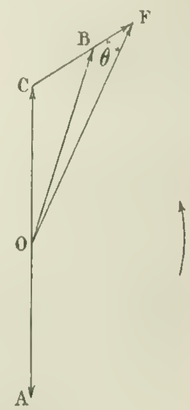


Fig. 28.

the maintenance of the torque in the main motor, and the application of load to the shaft automatically causes current to flow, hence there is no alternative but for a voltage to be present at the slip-rings and opposing that generated by the commutator machine, which implies that a certain slip has taken place; also, the greater the current necessary to provide the torque, the greater must be the slip. The commutator machine in part acts like a resistance, producing a slip proportional to the load. There are two essential differences between this and a resistance speed-regulation; one is that the energy input to the commutator machine, represented by the voltage at its terminals and the current passing through it, is converted to mechanical work, which may be utilized as desired, and secondly the current is not in phase with the voltage, which means that a wattless component is present. Naturally this component is used to advantage by making it of such strength as to act as the magnetizing current for the main motor, and thus to improve its power factor. In its simple form the series commutator motor, or slip regulator as it is termed, is a combined phase advancer and slip producer, the slip being proportional to the load.

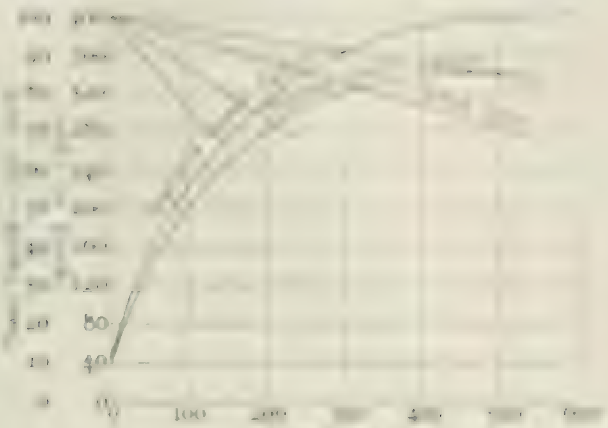
To extend its sphere of usefulness it is desirable to be able to adjust the slip-producing properties so that any required slip for a given load may be obtained, and at the same time to retain the phase-advancer properties under all conditions.

For this purpose the stator of the commutator motor is

[illegible]

The characteristics shown in Fig. 29 were obtained in the Testing Department of the British Thomson-Houston Company. The improved power factor at light load is not [illegible] is very considerable; the power factor also remains independent of the amount of speed regulation.

[illegible]



[illegible]

been possible. The slip regulator converts not only 90 per cent of the energy previously wasted into useful [illegible] the induction motor with [illegible]

[illegible] mounted on the end of the shaft [illegible] exciter, and its terminals are connected directly to the slip-rings of the main induction motor. As load [illegible] on the motor the secondary current flows through [illegible] full load may be adjusted by simply moving the core of [illegible]

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	27·5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
111	80·5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	100	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

A limit of slip frequency of 15 cycles per second is not necessary with resistance regulation. Rheostatic regulators are generally of the liquid type, and rapid action is therefore only possible when the operating motor is large and powerful and its internal losses correspondingly great. A regulator of this type is quite unsuitable for dealing with large and rapid fluctuations of power. A rheostatic regulator capable of meeting such conditions must be practically devoid of inertia and should preferably require very little power to work it. Such a regulator is now available and consists of suitable metallic grid resistances and electrically-operated contactor-type switches with current-limit control. It operates in a fraction of a second and keeps the current strictly within a definite prescribed limit, corresponding to the setting of the current-limiting relays. With the rotary regulator there is of course no time lag and the induction motor has the same characteristics as a compound-wound continuous-current machine.

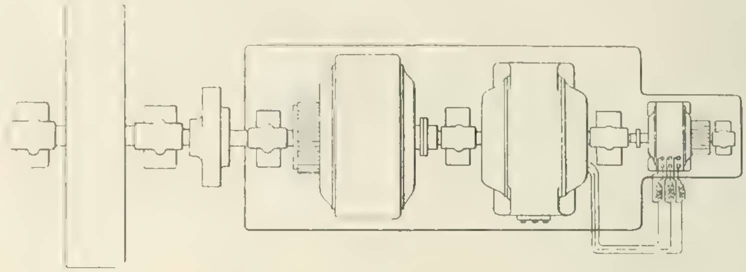


FIG. 30.

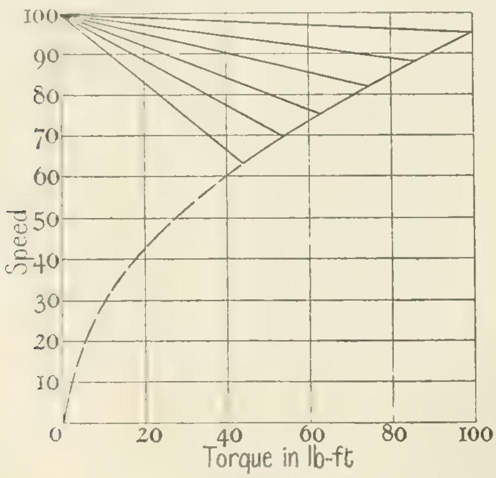


FIG. 31.

Another service is the regulation of an induction motor driving a ventilating fan, the torque of which is definite at each speed. As will be seen from Fig. 31, the speed may be varied by changing the motor slip-characteristic, which is effected by movement of the shunt cores of the commutator machine. The characteristics of regulation by this method are exactly the same as by resistance. To utilize the torque exerted by the commutator motor it may be coupled to the same shaft as the main motor, but preferably to a smaller high-speed induction motor. By adopting the latter course the commutator motor drives the direct-coupled induction motor over its synchronous speed, and electrical power is returned to the system.

This type of equipment may be built for any output.

THE SCHRAGE VARIABLE-SPEED SHUNT COMMUTATOR MOTOR.

There is one other type of motor introduced comparatively recently, the examination of which has been left until last, because it combines an induction motor and cascade-connected shunt commutator motor in one, and its action may be more readily understood after the preceding discussion.

Assume that the 3-phase primary winding of an induction motor is closed on itself, as would be the case in a continuous winding of the lap type ; the tappings at which voltage would be impressed are 120° apart. The secondary winding on the rotor is shown as three separate phases by $A\,A_1$, $B\,B_1$, $C\,C_1$, in Fig. 32.

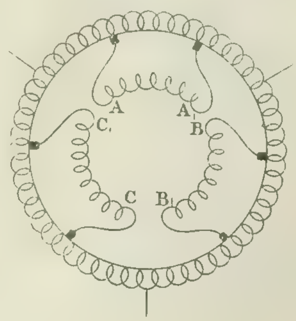


FIG. 32.

It has already been shown that to maintain a rotor speed lower than synchronism, there must be a counter electromotive force supplied to the rotor phases of the same frequency and opposite in sense to the voltage induced in them by the slip of the rotor relative to the primary field. There is a very simple and effective method of accomplishing this without an auxiliary machine, as will be clear from the following :—

Let a stationary commutator be fitted to the stator winding, the junctions of the coils being connected to the segments. Any pair of brushes pressing on the commutator will have a voltage between them the value of which depends on the angular separation or spacing. The frequency of the voltage depends on the speed of rotation of the main field relative to the brushes, and if the

[illegible] manner as an induction motor. A load torque retards the [illegible] current which provides the necessary torque.

It will be observed that the secondary current flows in [illegible] giving up energy by conduction to the primary, to which [illegible] operation, and the results produced are of fundamental [illegible] and uninfluenced by secondary voltages. By [illegible] reversing the sense of the voltage between them, the secondary voltage in the rotor phase is compelled to follow suit, and this necessitates that the rotor commence to [illegible] at a speed higher than synchronism. Under these [illegible] the torque-producing current in the secondary is in the same sense as the primary voltage derived from [illegible] primary to the secondary and converted to mechanical [illegible]

It will be observed that the functions of the primary winding are two-fold : first it induces voltage and transfers energy through the medium of the main field to the secondary, after the manner of an ordinary induction [illegible] and thus [illegible] power [illegible] to the [illegible] and [illegible] conducts additional power to the secondary when the motor runs above synchronous speed. The power dealt with by the commutator and through the brushes is only due to the slip energy analogous to the power dealt with by a separate auxiliary shunt commutator [illegible]

[illegible] a lower frequency than 50 cycles per second the speed range is increased.

This type of machine is only capable of satisfactory [illegible] ary resistance is appreciable compared with the reactance ; [illegible] being allowed. The second reason is that the secondary power factor may be artificially improved. It is shown in the discussion on the cascade shunt commutator motor that by tilting the counter voltage in phase relative to the voltage impressed, a wattless leading circulating [illegible] primary power factor improved to any desired extent. In order to do this with the machine under consideration, it [illegible] direction relative to the secondary. To be strictly accurate, the angle of phase shift should vary with the frequency, but as this is impossible a compromise must result, and as [illegible] speeds there is practically no [illegible]

[illegible] thetical machine since it is quite impossible practically to alter the spacing of brushes which are rotating in space. To utilize the idea, the primary and secondary must be [illegible] in opposite directions as shown in Fig. 33.

A still further modification is necessary in a practical machine. A straightforward primary winding after the [illegible]

operation with a normal supply voltage. Two distinct windings are therefore used in transformer relation, the one connected to the commutator having few turns and carrying correspondingly higher current, whilst the other may be star or delta wound and connected to the slip-rings.

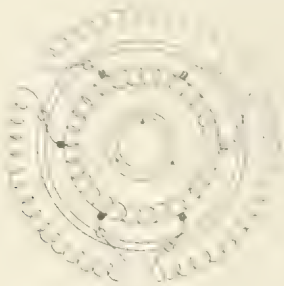


FIG. 33.

The practical limit of capacity for machines of this kind is in the neighbourhood of 70 h.p., and within this limit in the author's opinion it is the cheapest, simplest, and best variable-speed alternating-current motor with a shunt characteristic yet evolved.

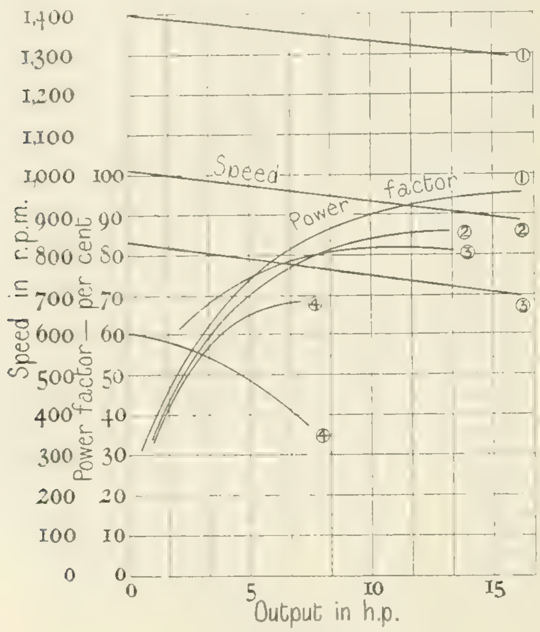


FIG. 34.

The characteristics shown in Fig. 34 are reproduced from the *Elektrotechnische Zeitschrift*,* four speed curves being given from the many obtainable within the complete speed range. The machine is essentially one which gives an output proportional to the speed, as may be readily deduced from its action above and below synchronism. The construction of circle diagrams other than for synchronous speed are somewhat difficult, but the solution becomes very simple by analytical methods.

The motor is specially suited for driving machine tools, pumps, fans, blowers, paper-making machinery, and printing presses.

* *Elektrotechnische Zeitschrift*, vol. 35, p. 89, 1914.

CONCLUSION.

Variable-speed motors of the shunt and series types are at present being manufactured in sizes up to 75 h.p. at 50 frequency, and in higher powers at lower frequencies, and in service are giving very satisfactory results. They are not inherently costly, and it seems very improbable that any other new type will be forthcoming to render them either cheaper or more simple. Between 75 h.p. and 200 h.p. the types available have a price per horse-power which seems to be prohibitive if judged by the number in operation. For outputs above 200 h.p. the induction motor with cascade commutator motor is probably the cheapest and best combination.

APPENDIX.

SERIES COMMUTATOR MOTOR.

The behaviour of the motor may be deduced from the consideration of a single phase so long as the influence of other phases is not neglected. In Fig. 35 a single phase of the stator and rotor is shown diagrammatically. The stator phase is displaced from the rotor phase carrying the same current by an angle α.

Let S = number of stator turns per pole per phase.
R = number of rotor turns per pole per phase.

For analysis the stator turns, S, may be separated into two components, one of which is along the armature axis in a compensating sense, and the other at right angles thereto exciting the armature phase. The compensating turns may be expressed as $S \cos \alpha$, and the exciting turns as $S \sin \alpha$, as shown in Fig. 36.

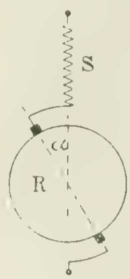


FIG. 35.

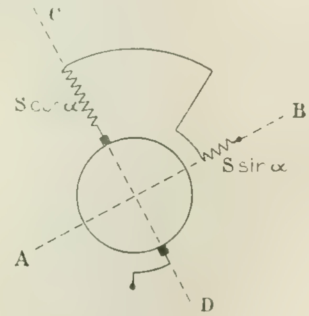


FIG. 36.

The compensating turns, $S \cos \alpha$, are not necessarily equal to the armature turns; the difference $(S \cos \alpha - R)$ may produce an excitation along the axis of the armature $= (S \cos \alpha - R) I$ ampere-turns, where I is the maximum current per phase.

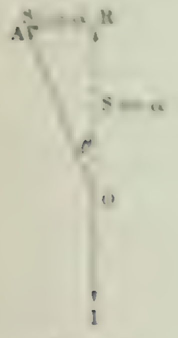
The excitation due to all phases of the exciting windings $= K S I \sin \alpha$, where K is a constant depending on the number of phases, and the excitation due to the difference between the armature and compensating turns of all phases $= K (S \cos \alpha - R) I$. These two excitations being at right angles in space the resultant excitation

$$= \sqrt{K^2 S^2 I^2 \sin^2 \alpha + K^2 (S \cos \alpha - R)^2 I^2}$$
$$= K I \sqrt{R^2 - 2 R S \cos \alpha + S^2}$$

[illegible]

[illegible]

[illegible] magnitude of the angle α.



[illegible] necessary to add vectorially those induced in the equivalent windings. The magnitude of the induced voltage in the [illegible]

[illegible]

and the value of the voltage induced in the armature and [illegible]

[illegible]

These two voltages are at right angles in phase, and their [illegible]

[illegible]

[illegible] the reactance pressure-drop, IX, [illegible]

[illegible] and the diagram must therefore be considered from this standpoint.

[illegible] position is fixed.

[illegible] current, and at extremely [illegible]

[illegible] losses, and also the output for all current values [illegible]

To improve the power factor the angle θ should preferably be negative, which would be the case with $R > S \cos a$. Unity power factor at normal running speeds is thus made possible by properly proportioning the parts.

The speed characteristic of the motor obtained in this way is for a definite angle a between the axis of the armature and that of the stator winding; by shifting the brushes a is changed, but upon this angle the angles θ and ψ of the vector diagram depend, hence the motor has a different characteristic for every brush position. To analyse the behaviour of the motor completely it is necessary to construct a series of speed characteristics each corresponding to a definite brush position.

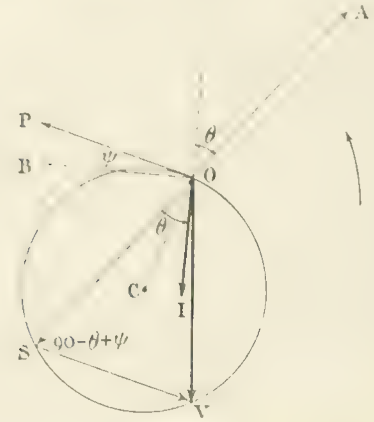


FIG. 39.

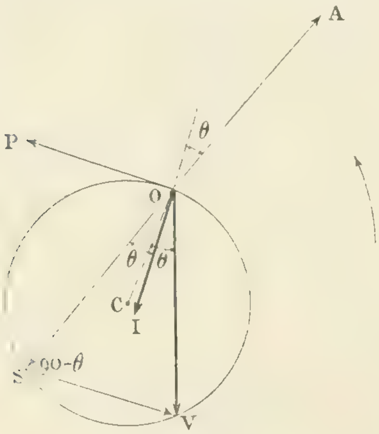


FIG. 40.

By reference to Equation (1) it will be seen that the induced voltage $I x$ may become large without the current I necessarily being large.

The reactance depends on the expression

$$R^2 - 2 R S \cos a + S^2,$$

which has a high value as a approaches 180°, when $\cos a$ becomes negative. In fact with normal designs the reactance is so high when $a = 180°$ that the input current is quite small even with the armature at standstill. In practice use is made of this circumstance by making it the starting position. The motor may be connected direct to the supply system and will take only a small current. As the brushes are shifted the current increases and torque develops, the motor eventually commencing to rotate against any initial load torque within its capacity.

The vector diagram, Fig. 39, illustrates the relations between the current and voltage when θ becomes negative, as would be the case in an actual machine.

Certain features which throw light on the general behaviour of the machine may be deduced by neglecting its resistance. With zero resistance $\psi = 0$ and the angle O S V of the vector diagram $= 90 \pm \theta$. Taking the

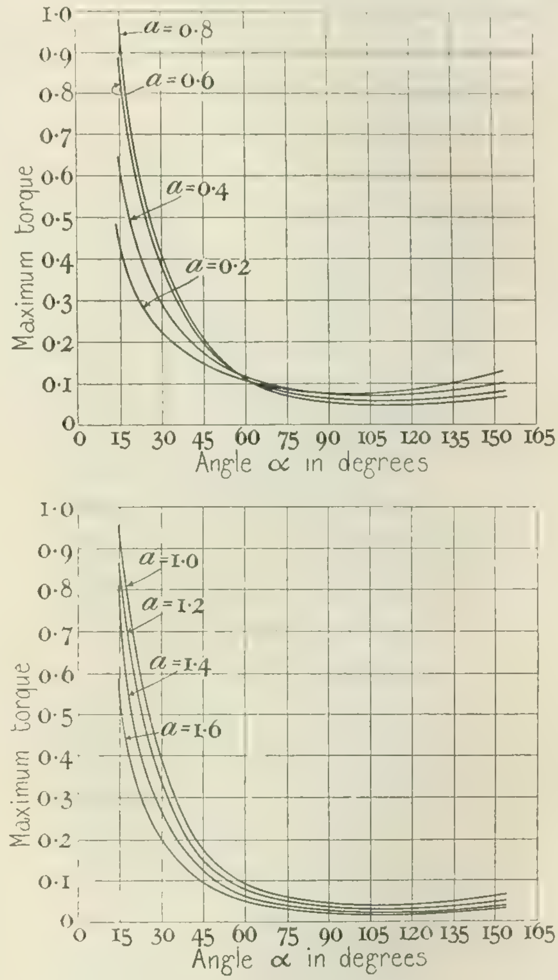


FIG. 41.

practical case, assume the angle O S V $= 90 - \theta$. The angle subtended at the centre of the circle by O V $= 2(90 + \theta)$, hence the angle V O C, where C is the centre of the circle, is equal to θ (see Fig. 40).

Also the diameter of the circle $= \dfrac{OV}{\cos\theta} = \dfrac{E}{\cos\theta}$.

Let the ratio of the armature to stator turns per phase $= a = R/S$.

$$\text{Then} \qquad \tan\theta = \frac{S\cos a - R}{S\sin a} = \frac{\cos a - a}{\sin a},$$

$$\text{and} \qquad \cos\theta = \frac{1}{\sqrt{1 + \tan^2\theta}} = \frac{\sin a}{\sqrt{a^2 - 2a\cos a + 1}}.$$

[illegible]

The maximum current is therefore

[illegible]

[illegible] that the range over which large torques can be produced is comparatively limited and is confined to small angles of [illegible]

DISCUSSION.

Dr. G. KAPP: The subject of this paper has been too long neglected. One reason for this may possibly be the [illegible] power on a large scale. The 3-phase induction motor was hailed as the universal solution of power distribution, and the absence of a commutator was considered to be its greatest virtue. One is naturally disinclined to give up [illegible] why the alternating-current commutator motor has not been taken up with enthusiasm in this country. Another reason is possibly the general difficulty of the subject from a theoretical point of view. An engineer wishing to design such a machine will find little help in the text-books on [illegible] articles in periodicals, mostly foreign, and then he finds it difficult to reconcile the statements of different authors, and this the more so, as each author uses a different [illegible] mastered the subject, and the author of this paper is one of them, fall into the error—most common with specialists—of assuming that their colleagues know all about the general principles and their practical application and that [illegible] waiting for some engineer to reduce the fundamental basis [illegible] self-evident and is represented with such uniformity in notation and graphic treatment that it may be copied from [illegible] tion of the subject has not yet been reached, each of us [illegible] the author are quite intelligible; and if we were dealing with asynchronous machinery no more would be required, for we have grown accustomed to read into the vector diagram the physical meaning represented by the different [illegible] accustomed to read into such diagrams also the correct physical meaning, but meanwhile I have found it useful for the understanding of treatises on commutator machinery to supplement the ordinary vector, or time, diagram by what [illegible] time diagram the vectors retain their length, but alter their [illegible] vectors retain their angular position but alter their sign and length. This is of course quite familiar to electrical [illegible] means of saving mental labour depends upon a general agreement on certain details such as direction of winding, sequence of phases, signs to distinguish vectors, etc. [illegible] grams the working of a commutator may be represented, not only in the abstract, but in a physical sense. The [illegible]

[illegible] are supposed to be wound in such a way that a continuous

current passing in at one terminal (or brush) and out at the other will produce a flux across the diameter in the same sense. In other words the exit terminal becomes a N-pole. The flux produced is represented (see Fig. A herewith) by a line parallel to the diameter of the winding. The length of the line should represent the crest value of the flux. The direction of the flux is represented by an open arrow-head. A little circle is placed at the other end of the line to show that it is a flux vector. The angular position of each flux vector does not vary, but where two or more fluxes are combined the angular position of the resultant flux vector changes. In other words the resultant flux vector rotates also in a space diagram.

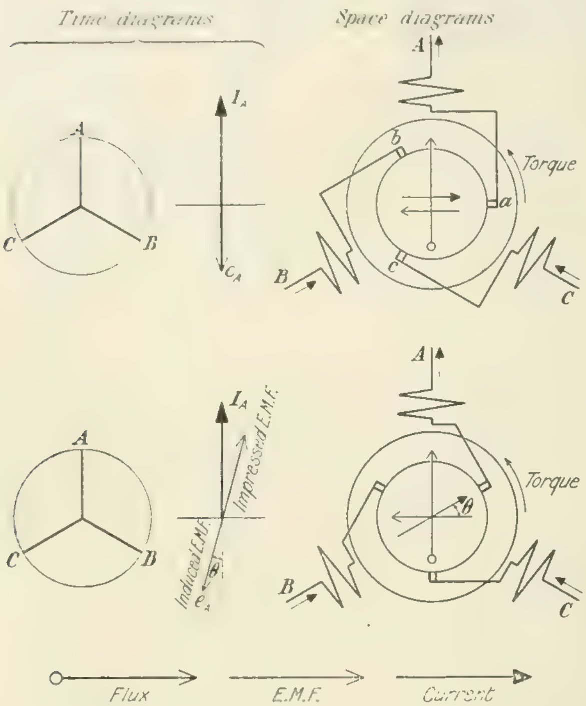


FIG. A.

Sense of rotation.—The time vectors rotate in a counterclockwise direction. To make the resultant flux vector also rotate in a counterclockwise direction in the space diagram the marking of the stator poles must be in a counterclockwise sequence.

Direction of electromotive force.—The direction of the electromotive force induced in the rotor is obtained by revolving the flux vector through 90°. The E.M.F. vector is represented by a line with an open arrow-head.

Current vector.—This is represented by a line with a closed arrow-head. Its direction is given by the terminal diameter, and its length and sign (whether to one side or the opposite side) is read off the time diagram.

Direction of torque.—Consider the current vector as a lever, pivoted at its tail and weighted at its head with the field flux; then the direction in which the lever turns is the direction in which the torque is exerted. The application of these conventional rules is shown in the diagrams (Fig. A). The motor is supposed to be provided with a compensating winding so that no flux is produced by the armature current, and the only flux vector appearing Dr. Kap
in the space diagram on the right is that due to the stator coils A, B, C. The diagram on the left shows the phase position. It is chosen for the moment so that the current in A has the positive crest value. The direction of the current in the space diagram is shown by the arrows placed to the field coils A, B, C, and the resultant flux is shown across the armature by the vertical flux arrow. The brushes are placed at right angles to the coil axes, and the resultant current through the armature is represented by the horizontal vector passing across the flux vector at right angles. This produces torque as shown by the curved arrow. The motion resulting from this torque produces the induced electromotive force, the space vector of which is also drawn at right angle across the flux vector, but with the arrow-head on the left. Since an arrow-head on the right of the current vector means a positive value (the current having the positive crest value at the time) the space vector of the electromotive force must be considered to be negative, and in the time diagram the E.M.F. vector must be drawn in line with the current vector, but in the opposite direction. We thus get for the A phase the very simple time diagram shown to the left of the space diagram (Fig. A). It consists of the current vector I_A and the vector of induced electromotive force e_A exactly opposite in direction; which is the condition for the working of the machine as a motor. To supply the motor with current we must impress an electromotive force which has one component equal but opposite to e_A; further, a co-phasal component to cover losses, and finally a component leading by 90° to balance the electromotive force due to self-induction. A motor with the brushes exactly at right angles to the respective field axes cannot therefore work with unity power factor. Let us now move the brushes forward through an angle θ, as shown in the lower half of Fig. A, and consider what happens. The flux and E.M.F. vectors remain in the space diagram as they were, for these quantities depend on the position of the stator coils, which have not been altered. The only factor that has been altered is the direction of the current vector. It crosses the flux line at an angle which is less by θ than the previous right angle. This phase difference exists between the current and the induced electromotive force, and is shown in the time diagram by the two vectors being no longer in line but containing the angle $180° - \theta$. The torque has been decreased in the ratio of 1 to $\cos\theta$, but a leading component $e_A \sin\theta$ has now been introduced, and this can be made to balance the electromotive force due to self-induction. The latter depends on the current and is independent of the speed; the leading component $e_A \sin\theta$ depends on the strength of the flux (and therefore on the current), the brush position, and the speed. It will thus be seen that only above a certain speed and load can the motor work with unity power factor, and that by suitable choice of load, brush angle, and speed, the machine, whilst taking power from the line, can at the same time inject a leading current into the line so as to make up for the bad power factor of some other motor connected to the same line. If the brush angle be increased to 90° the torque vanishes and the machine must be driven by external power. It then acts in the same way as a static condenser.

[illegible] With reference to the Latour shunt motor, I do not agree with the author that the [illegible] and rotor, a transformer with a movable secondary, and a set of choking coils with movable iron cores. The regulation can be effected by raising or lowering these iron cores. It is quite possible and also likely that excitation is actually effected by introducing exciting [illegible] be effected of course by means of a separate exciting winding on the stator of the machine, as shown in Fig. 19. I doubt, however, if on smaller machines this would be cheaper than using the rotor winding as [illegible] troublesome and expensive to manufacture. On large motors it may be necessary to have a separate exciting winding on the stator, as the commutators and brush-gear of such motors present in any case a very difficult problem. In this case, in addition to relieving the commutator of the increase of current, the whole of the regulation can be effected by altering the field current so that the switchgear used for speed regulation has only to carry the exciting current. This current can be kept within reasonable limits by choosing a higher voltage for the stationary field windings, as would be permissible if the exciting current were introduced in the rotor. I believe, however, that the Latour motor is only made for comparatively small outputs, say up to 50 horse-power; and for such outputs the introduction of the exciting current in the rotor gives a cheaper construction and is also preferable for electrical reasons. The author has given some diagrams for the Latour motor. I believe that Figs. 9 and 10 do not agree with the actual performance of this motor. The author himself says that a motor made in accordance with these diagrams would be impracticable, and it is therefore fair to assume that the diagrams do not represent the actual working conditions. He has given a possible solution of this discrepancy, but I believe that a satisfactory [illegible] prevents any [illegible]

Fig. B.

Fig. C.

[illegible] T S is greatly reduced under full-load conditions (Fig. B). [illegible] increase in speed increasing the effect of the excess turns in the rotor. The resistance drop P T gives a measure of the current and it is evident that the no-load current is now only a fraction of the full-load current. In considering the author's diagrams I find another point which is not quite to my liking. It is customary to give for [illegible] the assumption that the diagrams for the other two phases are like the one given but displaced in phase by 120°. It is of course desirable not to introduce currents or voltages of different phases in the same diagram, as this must necessarily lead to confusion. In Figs. 22 to 24 the author considers a phase O X 1, but he introduces voltages and currents of the phases O Z and O Y, with the con- [illegible] two. The exciting current in the same phase is of course a wattless current and is under 90° to the main voltage. If we introduce the exciting current flowing in the wind-

Dr. Kapp. ing O X for which the diagram is made out, the current O C will be displaced in the diagram by 90° and will come in its proper phase relation to the main voltage. As the flux is practically in phase with the magnetomotive force or with the exciting current that produces it, the flux will also be turned round in the diagram by 90°, and the electromotive force induced in the rotors by rotation, which is shown in the diagram in its correct position, will be practically under 90° to the flux. The diagrams given are time diagrams, and as the flux actually does not vary with the time, the position of the flux may be treated in different ways, but I believe that the way which I have just mentioned gives the simplest results and is less likely to lead to confusion than the method adopted by the author. It is usual to show it in this way in the ordinary induction motor, and there is after all no difference between the case where an electromotive force is induced by a field revolving relatively to the stator of an induction motor or by the electromotive force induced in the rotor of a commutator motor which revolves relatively to the field. The description of the Schrage motor given by the author is very interesting. The difficulty in this motor is, however, that it requires 6 brush spindles per pole. I suppose that the rotor must have a lap winding, so that no brush spindles can be omitted. A 6-pole motor would therefore require 18 brush spindles. This must make the brush-gear very difficult to construct, all the more so as the spindles have to be moved relatively to one another. In conclusion, I should like to state that the first patent ever taken out for 3-phase commutator motors was taken out in this country in 1888 by Wilson (No. 18,525), so that the 3-phase commutator motor is an English invention.

Dr. Wall. Dr. T. F. WALL: Although polyphase commutator machines are by no means a new invention, English literature dealing with this type of machine is exceptionally meagre. This paper is therefore of special interest and contains a valuable fund of suggestive information. The subject is a very wide one and I propose to confine my remarks to the Eichberg shunt machine and the series machine. In passing, however, it might be well to point out that the vector diagram of Fig. 10 shows the machine acting with a slight generator effect and not as a motor running at no load as stated in the text. For a purely unloaded motor, the current vector I should be at right angles to the electromotive force due to rotation, that is to the vector S Q. As regards the Eichberg shunt motor shown in Fig. 13, there is an interesting point which comes into question with reference to the direction in which the motor will run. Fig. D is similar to the author's Fig. 13, with the exception that the auto-transformer windings are continued beyond the star point. In Fig. E the vector diagram is shown for the current I in the compensation and armature windings and the applied pressure E per phase when the motor is standing still. The number of turns in both compensation and armature windings being the same, the back electromotive force e_r of the rotor will be equal to the back electromotive force e_s of the stator. The conditions are those of a short-circuited transformer. Now suppose that the pressure, above the star point, of the tapping A of the auto-transformer is the same as the pressure at the corresponding brush of the motor. If the brushes are connected to the points A no current will be supplied by the transformer to the motor and consequently there will be no torque. Hence the vector diagram of Fig. E will remain unaltered. Next suppose that the brushes are connected to the tappings B which are at a higher potential than the tappings A. In this case a magnetizing current will be supplied by the auto-transformer to the rotor such that the corresponding rotating field is sufficient to induce a back electromotive force e_r', which added to the internal drop e_r will be just equal and opposite to the applied pressure. An electromotive force e_s' equal and opposite to e_r' will be induced

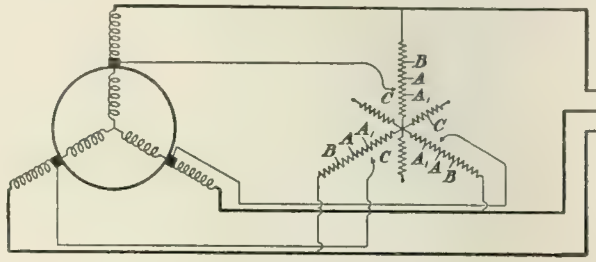


FIG. D.

in the stator and the vector diagram will be as shown in Fig. F, the magnetizing current being indicated by i_u. The motor will begin to run, and the direction of rotation obviously must be such that the total back electromotive force is increased. This will happen if the electromotive force e_r' is increased, that is to say, the rotor will revolve in the direction opposite to that of the rotating field. Considerations of commutation would make this direction of rotation generally inadmissible in practice. Now suppose that the electromotive force applied to the rotor by the auto-transformer is less in magnitude than the value of e_r; for example, suppose the armature is short-circuited by connecting the brushes to the star point of the auto-transformer. The pressure at the brushes will disappear and a magnetizing current will flow in the stator winding such that the corresponding rotating field

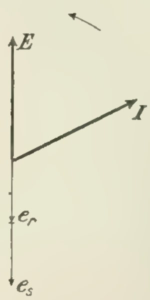


FIG. E.

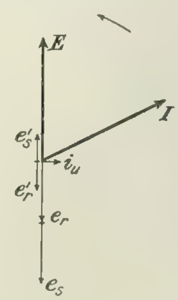


FIG. F.

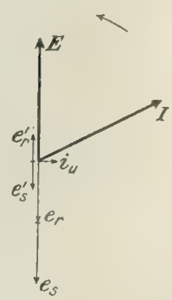


FIG. G.

will induce an electromotive force e_r' in the rotor to supply the internal pressure-drop e_r. The vector diagram will be similar to that shown in Fig. G, which refers to the starting conditions for the case in which the brushes are connected to tappings A', intermediate between A and the star point. In Fig. G the vector e_s' represents the electromotive force induced in the stator by the rotating field, and is equal in magnitude and opposite in sign to

[illegible] tion of the ratio of the transformer which couples the rotor to the stator circuit. There is, however, another way which is much more convenient. This method is due to [illegible]

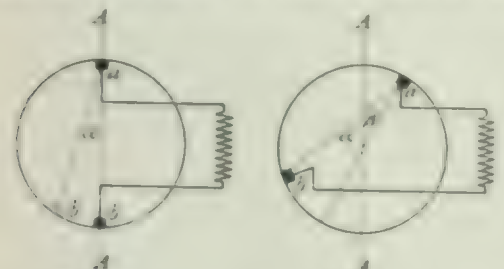


FIG. [illegible] FIG. [illegible]

supplying one phase of the rotor, and the brushes are shown diametrically opposite and in the short-circuit position. Let u_0 be the transformation ratio under these conditions. If the brush a is kept fixed and the brush b [illegible] of displacement of the brush axis, and the transformation ratio has now become $u_0 \cos a$. The stability limit of speed is therefore given by

$$\frac{\omega}{\omega_0} = 1 - \frac{\cos a}{u} = 1 - \frac{\cos a}{u_0 \cos a} = 1 - \frac{1}{u_0}$$

[illegible]

[illegible] the method of [illegible] which has to be allowed for. [illegible] is identical in principle with the ordinary [illegible] motor the voltage impressed on the rotor is [illegible] the Schrage motor the voltage is va[illegible] axis of the stator and the rotor w[illegible] different with different motor speeds. [illegible] the columns headed "watts"* should really be "kilowatts"; even then, taking the last set of figures, 500 watts for [illegible] other, they must have the same [illegible] missed the point that the author wished to bring forward. Turning to the theory of the series commutator motor at the end of the paper; on page 455 the author says, "To [illegible] stator and rotor in[illegible] The voltages induced are merely the reactance voltages, and these are always at right angles to the current. Since all the coils are in series, there is only one current, and there-[illegible]

[illegible] discussed in the paper an ap[illegible] was a lack of appreciation of the [illegible]

* [illegible]

an effort to run small single-phase commutator motors on the City of London Company's 83-cycle circuit, which, as might be expected in the light of our present knowledge, necessitated daily attention to commutators and brushes. While many of these defects have been largely overcome in recent years in connection with single-phase motors, I believe that I am correct in saying that few, if any, of them apply to 3-phase motors, and I should be glad if the author in his reply would make a definite statement in this connection. There is, in my opinion, no more difficulty in obtaining good commutation from the 3-phase commutator motor than from an ordinary continuous-current motor. If this were fully realized, I think that the 3-phase commutator motor would be more widely adopted where efficient speed regulation is required, than is the case at present. I should particularly like to emphasize the importance of the application of the shunt commutator motor, referred to on page 449, in combination with a large slip-ring induction motor, for obtaining efficient speed regulation over a considerable range, together with an improvement in power factor. The very interesting practical application of the series commutator motor, referred to on page 451, is also noteworthy when used in conjunction with a large induction motor as a slip regulator, for producing slip as a function of the increase in load on a motor flywheel combination, so as to enable the flywheel to take the peak of the load and give up energy by reducing the speed of the induction motor. This slip regulator can also be used at the same time to obtain a measure of power-factor correction. The important factor in the use of such a slip regulator is that the reduction in speed is obtained without loss of energy, whereas heretofore it has been necessary to use a slip regulator of the rheostatic type in which energy was dissipated either in a liquid or metal resistance. In some cases, owing to the difficulty of obtaining sufficiently rapid action of the ordinary motor-driven type of automatic slip regulator with liquid resistance, it had been necessary to include in the rotor circuit of the induction motor a permanent resistance, absorbing as much as 10 per cent of the total energy supplied to the motor continuously. This is a new application, the importance of which is not yet fully realized, but it will have an important bearing in the future on rolling-mill and winding-gear equipments in which a flywheel motor-generator combination is used.

Mr. Rushton. Mr. A. RUSHTON (*communicated*): The author, in the Appendix dealing with the series commutator motor, shows that in order to improve the power factor the angle θ (by which the rotational voltage differed in phase from the current) should be made negative. If, however, the power factor be increased by this means, the speed at which the motor becomes unstable is also increased. That this is so can be seen from a consideration of Fig. 38, which is the diagram for a stable motor, and Figs. 39 and 40 which represent the case of a motor unstable at low speeds.

$$\text{Torque} = \text{constant} \times I^2 \sin \alpha.$$

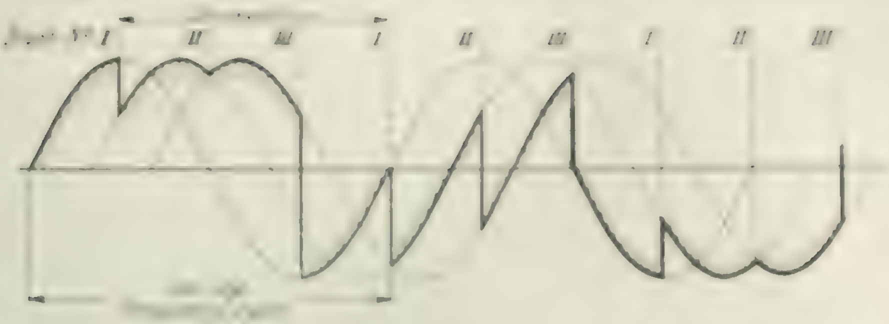
The line S V in the diagram is the component of the impressed voltage overcoming the impedance pressure-drop, and therefore the current I is directly proportional to this voltage. Thus

$$\text{Torque} = \text{constant} \times (S\,V)^2 \sin \alpha.$$

Mr. Rushton. At standstill S V = O V = E, the impressed voltage, and from Fig. 38 it will be seen that, as the speed increases, S V continually decreases, and therefore the motor has its maximum torque at the start. In Fig. 39, however, S V has its maximum value when equal to the diameter of the circle, which is greater than the chord O V, and therefore the torque will at first increase as the motor runs up to a certain speed, and afterwards the torque will decrease as the speed increases, the motor becoming stable. Thus, increase in power factor is only obtained at a certain sacrifice in stability, which, however, in many cases may be unimportant. On page 445 the author states that it is necessary, for reasons of commutation, to ensure that the armature rotates in the direction of the rotating field. There is also another reason why this may be advisable. When the armature rotates with the field the torque produced by the currents in the coils undergoing commutation is in the same direction as the main torque; while when the armature rotates against the field, the torque due to the short-circuit currents opposes the main torque. Thus, in small machines quite different results may be obtained depending upon whether the angle α is on one side or the other of the short-circuit position. I should like to know whether this effect is at all appreciable in the larger machines. As the author mentions the use of series commutator motors in connection with ventilating fans, blowers, and pumps, perhaps he can say how they compare in efficiency and cost with the motors generally employed for this class of work.

Mr. Catterson-Smith. Mr. J. K. CATTERSON-SMITH (*communicated*): This paper is one of considerable value, and is most welcome at the present time both on account of its intrinsic interest and because it indicates that British manufacturers are constructing for special purposes polyphase commutator motors, a type of machine developed almost exclusively abroad. In spite of its many valuable characteristics the polyphase commutator motor has been left severely alone in the British Isles, and I doubt if a single manufacturing firm in the country lists these motors. This is, I believe, the first important paper on the subject presented to the Institution, and it seems to me a matter for regret that its reading has been confined to one Local Section; in my opinion it would have been appreciated at other centres. I suppose the principal causes of the neglect of this type are: (1) Comparative complexity and costliness of these motors —a 10 h.p. 1,000 r.p.m. shunt motor with ± 50 per cent speed regulation costs £70 or £80; (2) difficulties in securing perfect commutation; (3) lack of experience with these motors, the type being almost non-existent in Engineering Colleges and almost exclusively manufactured and tested abroad. The greatest obstacle to successful performance is commutation, which becomes increasingly severe as the size goes up; although this is mentioned on page 442 in connection with the Latour motor outputs, and on page 443 for the Eichberg motor, unfortunately the author does not give any information as to what can be done to provide a commutation or reversing flux to prevent the brush short-circuit currents. It must be remembered that under all conditions of working there are coils periodically short-circuited by a brush, and although use may be made of hard brushes, single-turn coils, and resistance commutator risers, it is only in small sizes that operation is beyond criticism. The variation of current in any one coil of a

[illegible]



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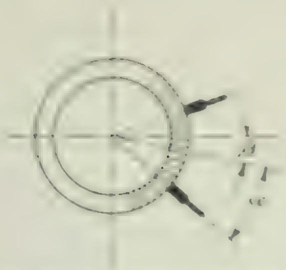

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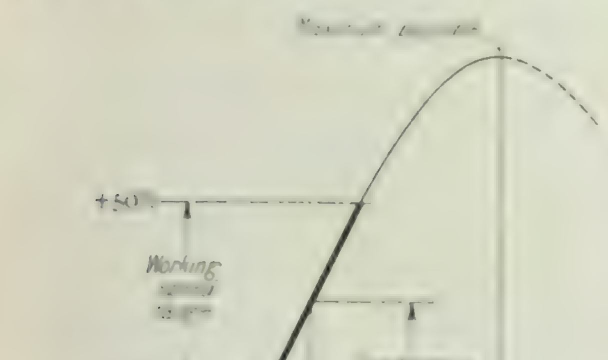

which happens to be running at a speed such that one [illegible]

electromotive force will prove troublesome is due to the [illegible] 0·10 volt, *i.e.* 0·30 volt between [illegible]

[illegible] no-load speed of this type of shunt motor is given by

r.p.m. [illegible]

where K_c = commutator winding diametric E.M.F. coefficient [illegible]

Z_c = total conduct[illegible]

f_1 = line frequency, [illegible]

The relation between the no-load speed and the brush [illegible] line. This permits the simplification of the above exact [illegible]

[illegible] ing between brushes (displaced by a), then,

[illegible]

[illegible] motor tends towards series [illegible]

are shown; in this case the brush displacement α is varied whilst the brush rocker angle β is kept constant. At the [illegible] page 454 the author says that the construction of the circle diagram is difficult; that this statement is hardly correct is indicated, I think, by the following construction

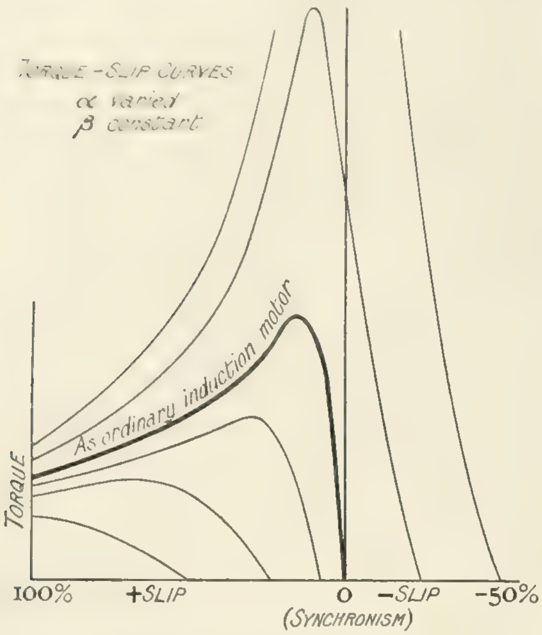

FIG. N.—Torque and Slip Curves.

for the approximate locus of the current vectors, shown in Figs. O and P: (1) Set off, in Fig. O, the length O A = (line volts) ÷ (total reactance); this is commonly called the ideal short-circuit current, but is, I consider, better termed

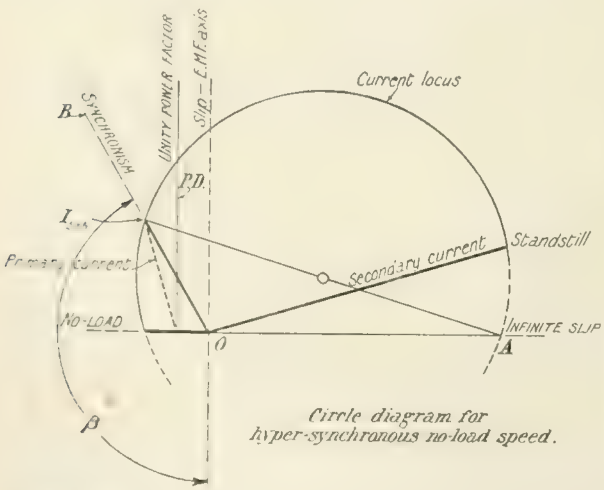

FIG. O. Circle Diagram for Shunt Motor at High Speed

the secondary current at infinite slip. (2) Set off O B at β (see Fig. L) to the slip-E.M.F. vector line, and along O B mark the secondary current when the motor is revolving synchronously, that is, $I_{syn} = E_c/R$, where E_c is the commutator voltage between brushes (continuous-current volts at this particular speed). (3) Join I_{syn} and A and bisect to find the centre of the circle; this gives no-load current, etc., with the same order of accuracy as the standard circle for a simple induction motor. In Figs. O and P the circle is shown full line for the "motoring" portion, the remainder being dotted; only the secondary current vectors are shown. It appears to me that in many instances, where it is important to work at high power factors, this type of

Mr. Catterson-Smith.

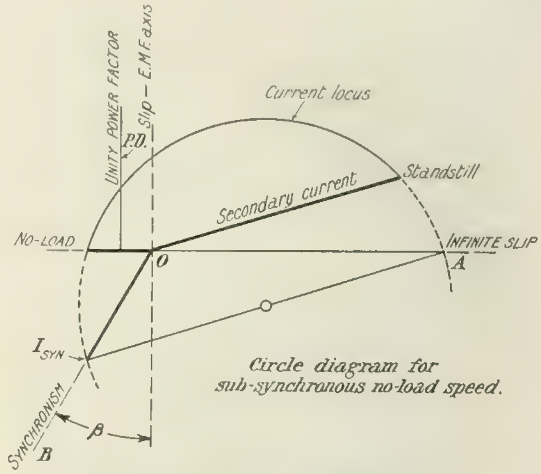

FIG. P.—Circle Diagram for Shunt Motor at Low Speed.

motor is a much simpler proposition than the installation of induction motors with phase advancers, especially in the smaller size of machines. It is, I think, not widely realized that unless the open-circuit rotor volts are made objectionably high, the phase advancer will have to deal with enormous currents because on load the rotor volts drop to only 2 per cent or so of their open-circuit value, and thus to have the commutator at some distance from the main motor appears to me to be bad practice.

Mr. N. SHUTTLEWORTH (*in reply*): Dr. Kapp has noticed the many notations adopted by authors on this subject. It is almost impossible for this reason, when the time at one's disposal is limited, to digest the existing literature, and the references made by some speakers to the vector diagrams in the paper cannot receive a more adequate reply than is given by Dr. Kapp. His suggestions for a standard notation are both simple and clear, and if generally adopted will prove of great value.

Mr. Shuttleworth.

Dr. Kahn's remarks on the Latour motor are not at variance with the opinions expressed in the paper. It is stated that one essential for successful operation and good characteristics is that the angle θ should vary in direct proportion with the load current. This is simply another way of saying that the leakage reactance pressure-drop must be completely neutralized at all loads and speeds, and with this object in view the arrangement of Fig. 12 is suggested. Figs. B and C in Dr. Kahn's remarks show that by reducing the leakage reactance pressure-drop the characteristics are much improved, but the method he suggests of neutralizing this pressure-drop, although probably employed in practice on small machines, is not perfect. By under-compensation the effects produced are proportional to the speed of the motor; thus, while at one speed the reactance pressure-drop may be neutralized,

[illegible]

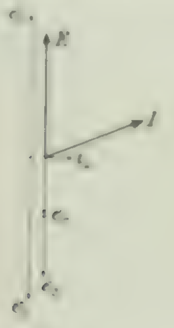

Fig. Q

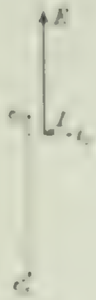

Fig. R

Dr. Wall has been led to erroneous conclusions by [illegible] motor as shown in Fig. D, by connecting brushes on the motor to tappings on the exciting transformer, which should only be used for over-synchronous running. If the motor be assumed on light load a running condition is obtained [illegible] operation may best be seen by considering the brush connected to a point C on the exciting transformer on the opposite side of the star point. The voltage impressed on the stator winding is then greater than the star voltage of the supply system, and the field produced in the motor must induce in the stator and rotor windings counter voltages which are equal and opposite, but of greater magnitude than the star voltage of the system. These are represented as e_s', e_r', in Fig. Q. Instantaneously, there is no alteration to the counter voltage of the machine. The torque produced by the newly-formed field causes acceleration of the armature, and the direction of rotation will be such as to reduce the magnitude of the short-circuit current I which is flowing, and the armature will continue to accelerate until this current has practically vanished. If the current decreases, the reactance pressure-drops e_s and e_r must decrease also, and finally become negligibly small, but as the full counter voltage of the machine must be provided at all times, a reduction in the values of e_s and e_r must be accompanied by a reduction in the value of e_r', [illegible] armature phase, which indicates that the motor rotates

[illegible] sets of brush-gear were shown to be chiefly commercial, in [illegible] and a transformer with a capacity equal to the input of the [illegible] claimed over the ordinary type of motor for fan drive as the latter motor is then quite stable at low speeds.

Reference is made by Mr. Jakeman to the commutation of the series type of motor during starting. Complete satisfaction in this respect will be obtained if the capacity of the motor does not exceed the limit of output given; it is naturally one of the limitations taken into account by the designer. A Schrage motor cannot be said to be identical in principle with the ordinary shunt commutator motor; these motors have in fact differences which are [illegible] and 5 of Table 2 are in kilowatts and represent the output of the commutator machine, which reverses its function when the induction motor with which it is connected runs light; it delivers current to the [illegible] motor for excitation purposes. [illegible] due to exciting current, which is given by [illegible] as generator, to the induction motor. [illegible] which this speaker refers on page 439 is not so clear as was intended, it should be added that in changing from a delta-connected armature to a star-connected armature, by reducing the turns in the ratio of $\sqrt{3}$ to 1, the resulting [illegible] stator because the distribution would differ from that of [illegible] number of turns. The solution of the statement made on page 455 is not quite so simple as Mr. Jakeman seems to think. The circuits in the phase considered are not only linked by the flux due to the current in that phase, but by fluxes due to other phases, and the resulting effect is not at all [illegible]

[illegible] between the two. There is one other defect present in [illegible]

[illegible] this voltage cannot be neutralized except by the use of external apparatus. This fact, more than anything else, has led to the general belief that the successful commutation of alternating current is very difficult. Fortunately, in polyphase machines the conditions for the neutralization of the voltage mentioned are inherent, and when the main principles are correctly applied, the difficulties do not exceed those of continuous-current machines. We have had an alternating-current commutator machine giving good commutation when generating no less than 25 volts between segments, and collecting current which gave a calculated reactance voltage of commutation 50 per cent higher than is used on the best rotary converters or continuous-current generators on the market under full-load conditions.

Mr. Rushton is quite correct in stating that good power factor is antagonistic to the maintenance of stable running at low speed in the series commutator motor. In a commercial motor a good power factor is desired, hence there is necessarily a minimum speed at which such a motor may be expected to maintain full torque, and this, as shown in the paper, is generally in the neighbourhood of one-third maximum speed. The short-circuit currents under the brushes in motors of appreciable size are usually so low that the addition to the normal torque of the motor may be neglected. The efficiency of a series motor, neglecting the commutator, is comparable with that of an induction motor, and the losses on the commutator reduce the overall efficiency by about 2 per cent. Mr. Shuttleworth.

The formula given by Mr. Catterson-Smith for the no-load speed of the Schrage motor appears to be in error, and I would suggest instead :—

$$\text{r.p.m.}_{\text{no-load}} = \frac{120\, f_1}{p}\left[1 \pm \frac{K_c}{K_2} \cdot \frac{Z_c}{Z_2} \cdot \frac{\sin \alpha}{p} \cdot \frac{1}{k}\right]$$

where k is in the percentage of total flux entering the secondary.

Having always determined the characteristics of this motor by analytical methods, I had not imagined that the solution by the circle diagram could be made so simple as that given. No doubt great pains have been taken to establish its general accuracy, and as such it is welcomed as a distinct acquisition to the paper.

CALCUTTA LOCAL SECTION: CHAIRMAN'S ADDRESS.

By W. H. EVERETT, Member.

(*Address delivered* 28 *January*, 1915.)

(In the absence of the author, owing to indisposition, the address was read on his behalf by Mr. A. K. Taylor, Vice-Chairman.)

Much has been said recently as to the possibility of taking advantage of the war in order to develop existing industries in India or to start fresh industries, and this leads me to touch on the state of the electrical industry in this country. As is well known, electrical engineering is based largely on the scientific discoveries of an Englishman, Faraday; and England took a leading part in the series of inventions and the other extensive pioneer work involved in placing the new industry on a commercial basis and transferring operations from the instrument maker to the engineer. The fact that our lead was not fully maintained subsequently and that one or two competitors outstripped us in some directions as the development of the industry proceeded has been attributed to various causes, such as the absence of protective duties, lack of enterprising financial support, restrictive legislation, and deficiencies in technical education. Passing by such controversial questions, it will be sufficient to mention that German electrical exports in 1913–14 totalled £14,500,000. Much of this trade might be captured by England; but it may be admitted at once that India has no chance of taking part in the capture.

The electrical manufacturing industry may almost be said to be non-existent in India. The nearest approach to it is to be found in such establishments as repair workshops attached to tramways and other power stations; but such workshops exist, of course, merely for the special purposes of these particular concerns and not for the supply of goods for the market. The experience and practical training afforded in these shops provide, however, valuable stepping-stones towards the initiation of an electrical manufacturing industry in case the conditions and commercial prospects should justify this in the future. It is well known that nearly all the steam-engines in use in India are imported, though a few of simple type are made by local firms. For similar reasons it is unlikely that electrical manufacture on any large scale will be started here in the near future, though repairs will in many cases have to be done locally, as at present. Bearing in mind, among other considerations, that highly qualified designers and other skilled assistants, who would have to be recruited from other countries, would be expensive, and that labour is cheap, it would appear that the most promising field for electrical manufacture would be work of a simple repetitionary character. It is hardly necessary to mention that certain forms of electrical instruments for telegraph work are made here in considerable numbers; and as to the feasibility of training native labour in the skilful execution of repetitionary mechanical operations of an elaborate and complicated nature, I may refer to the

[illegible]

Another factory, which adjoins a copper mine under the [illegible]

[illegible] both drawn and squirted wires being imported. Large factories in Kawaschi and Osaka are turning out tens of thousands of lamps daily, yet not enough to meet the [illegible]

[illegible] insulating materials other than porcelain, ebonite is the [illegible] grades of mica are imported from India through London firms. India-rubber insulating tapes are made in many places, but mostly only on a small scale and in a primitive way. Insulating compounds and varnishes are only made [illegible] Insulated copper wires and cables of all ordinary description and sizes are made locally to the almost entire exclusion of imported goods. Measuring instruments are almost all imported. Factories are defective in their [illegible]

[illegible] electrical industry [illegible] serve to indicate broadly the lines on [illegible]

[illegible]

[illegible] deduced the particulars given below. Previous to 1912–13 the present system of classification was not [illegible] available.

[illegible]

	1913–14			
[illegible]				
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Cables and wires	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Other apparatus	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]		
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

trade; but on the whole the Indian electrical trade is supplied almost entirely by England. Leaving aside telegraphs and telephones, we see that there was an increase in every item, except generators; this exception is doubtless explained by the completion of the big generating station at Cossipore for the Calcutta supply. The total increase in imports in the one year was 34 per cent, and the total electrical trade in 1913–14 exceeded one million sterling.

In the details of the imports the more noteworthy points are: the increase of lamps from Austria was 160 per cent in the year; the increase in "other apparatus" from America was 1,500 per cent in 2 years; motor imports from Germany decreased by 57 per cent in the year; and the imports of "other machinery" from England increased 115 per cent in the same period.

It is interesting to see how the electrical imports are divided among the different Provinces, and the following table gives the chief particulars:—

PERCENTAGES OF ELECTRICAL IMPORTS IN 1913–14.

	Bengal	Bombay	Madras	Burma
Fans	61	21	5	9½
Lamps	45	22	11½	17
Cables and wires ...	45	38	9	7½
Other apparatus ...	39	46	8½	5
Generators	43	26	15	9½
Motors	49	27	20	2
Other machinery ...	36	47	11	5
Average ...	45½	32½	11½	8

Thus the four Provinces named above took 97½ per cent of the total electrical imports (excluding telegraphs and telephones) in 1913–14. The data on which these figures are based refer only to British India, particulars for Kashmir and other native states not being included.

Although practically no electrical machinery is made in India, the advantages of electricity for various purposes are becoming widely known; and extensive developments have already taken place in this country, and are now proceeding, in electrical distribution for both lighting and power. This branch of the electrical industry is far more important than the manufacturing branch, and, unlike the latter, is indispensable for the full industrial advancement of a country—just as railways are vital factors to industry whether locomotives are made locally or imported. I have already pointed out that electrical power schemes in Japan have mainly been carried out with the aid of imported machinery, and as additional examples I may quote the case of Sweden and Norway, where electrical development has been remarkably rapid, in spite of the fact that electrical manufacture has not been conspicuous in either country.

It will be convenient to summarize here the more important public schemes now in operation in India, or to be started in the near future. The data are collected from Mr. Partridge's paper read before this Local Section in January, 1914.*

* T. G. PARTRIDGE. Some notes on the principal electrical undertakings in India, Burma, and Ceylon.

The chief plants operated by water power are:—

Tata Power Co., Bombay ...	... 32,000 kw.
(To be increased subsequently to 100,000 kw.)	
Cauvery Falls, Mysore	... 12,400 ,,
Jhelum River, Kashmir ...	... 4,000 ,,
Darjeeling	... 2,500 ,,
Mussoorie...	... 1,900 ,,
Simla	... 750 ,,
Jamau, Kashmir	... 700 ,,

The total power of these seven installations is thus about 54,000 kilowatts or 71,000 horse-power.

The principal stations worked by steam power and oil engines are as follows:—

Calcutta	... 14,800 kw.
,, tramways	... 2,900 ,,
Bombay, including tramways ...	... 9,000 ,,
Rangoon, ,, ,, ...	... 5,400 ,,
Madras, ,, ,, ...	... 3,800 ,,
Colombo, ,, ,, ...	... 1,550 ,,
Kolar Mines Co.	... 1,500 ,,
Dacca	... 900 ,,
Delhi, including tramways ...	... 840 ,,
Cawnpore, ,, ,, ...	... 850 ,,
Gwalior	... 700 ,,
Lahore	... 600 ,,
Kandy	... 540 ,,
Mandalay	... 520 ,,
Bikanir	... 500 ,,

The total rating of these stations amounts to about 58,000 kilowatts (77,000 horse-power), of which about 1,800 kilowatts is generated by Diesel oil engines, eight in number, distributed among six stations.

Some of the longer distances of transmission are detailed below, together with particulars of the pressures of generation and transmission, and the frequencies used:—

	Distance in Miles	Voltage of Generation	Voltage of Transmission	Frequency
Cauvery Falls ...	92 58 40	2,200	35,000 32,500 21,000	25
Jhelum River ...	55	2,300	30,000 60,000	—
Tata Power Co. ...	43	6,600	100,000	50
Simla	21	2,200	15,000	50

It will be seen that electric power is already being transmitted in India to distances of the order of 50 to 100 miles, with the use of appropriate extra high pressures, the generators being driven by water power. Waterfalls, whether natural or artificially derived from a steeply sloping river-bed or a storage reservoir, are rarely to be found at the spot where power is wanted, and the capital charges of an installation (especially for transmission mains and allied costs), as well as the running expenses, place a limit on the distance to which power can be transmitted on a profitable commercial basis. This limit must obviously depend on various factors, such as the

[illegible]

of the Tata Company).

From a very rough estimate that I have made, based on the local rainfall and the available head of the water, [illegible] Central and Southern India represents a total power of the order of 100 million horse-power averaged through [illegible] bounding the whole of Northern India represents possibly 1,000 million horse-power. Of course only a small fraction of this power could be commercially utilized. The conditions for commercial feasibility are that the fall must be fairly concentrated (though there are cases where sufficient fall can be obtained by utilizing the slope of some miles of river), and the contour of the land must be such as to make it possible to construct a reservoir of adequate capacity, if the smallest flow of the river in the dry season [illegible] layas there is some natural storage in the form of ice and snow, which tends by melting to maintain during the hot weather the flow of the rivers fed from that region, and to reduce the flow in the cold season.

As regards the value of the hydraulic power, assume that about 1 per cent of the total power could be utilized [illegible] ably sold for from £4 to £7 in the case of large economical plants in other countries, after allowing for interest and depreciation as well as wages and all other expenses. The profit is probably from 6s. to 10s. per horse-power per annum. Or, to look at the question in another way, the cost of coal per horse-power sold per annum in a large electric power station, with coal [illegible] economical load-factor usual in such cases. Thus the 10 million horse-power assumed to be available would be worth about five to fifty million pounds sterling, depending

[illegible] I believe, been [illegible] authority that it is doubtful whether there will be in India the extensive demand for nitrates as fertilizers that has arisen in some other countries, still it seems worth [illegible] parts of the world with this [illegible]

[illegible] years ago, and now the power absorbed there in this industry on one system alone amounts to about 300,000 horse-power, divided among five power stations. For [illegible] The raw material is the air, from which the nitr[illegible] abstracted, the heat required for the combinat[illegible] produced by means of electric arcs or inca[illegible] into Italy, Switzerland, France, Germany, Japan, and [illegible] 200,000 horse-power, and very large extensions are proposed. As soils become impoverished and as the supply of natural fertilizers diminishes, the importance of this question will become greater and greater. In the last [illegible] 100 tons of air [illegible] 50 times this quantity.

As regards electric traction, it appears that very important developments may be expected in India at [illegible] are equally suitable and promising.

It is hardly necessary to add that those whose occupations are connected with steam-locomotive engineering need have no apprehension that their employment is coming to a speedy end; for a very long time will certainly elapse before electricity can make any attempt to compete with steam on the typical Indian railway, with its great distances, long intervals between stations, and infrequent train service. The electrification of some of the hill railways might well be considered, though it is obvious from a cursory glance that the convenient proximity of water power was not one of the factors taken into account when the sites of our present hill stations were chosen.

The advantages of electric transmission in factories are fairly generally recognized, and many examples are to be found here in Government concerns, railway workshops, engineering works, and elsewhere. For the special requirements of jute mills electric driving does not find wide favour. I have not examined the question in connection with the particular conditions of this industry, but it is not unnatural that most of those responsible for the running of these mills should give preference to the system with which they are thoroughly familiar, and which answers well, unless and until they are compelled by the force of competition or by reduced profits to consider a different system of power transmission.

On the other hand, of the 83 cotton mills in Bombay, 26 are to be driven by electric power from the Tata Company's system, and it is anticipated that the steadiness of the drive will give increased production and improved quality of yarn and cloth. The price for power in Bombay is to be as low as 0·55 anna per unit, a rate which makes electricity a very formidable competitor with other methods of power supply. In Madras the cost is for very large consumers 0·75 anna per unit, the generators in this case being steam-driven.

In Calcutta the rate of electric power used for industrial purposes is 8 rupees per kilowatt per month plus 0·5 anna per unit; for a factory operating 10 hours a day this works out to 0·93 anna per unit. For large installations in certain cases the rate is on a sliding scale, which may be as low as 0·4 anna per unit.

In reply to my enquiries as to the electric power utilized for various purposes in Calcutta Mr. R. E. Winkfield, Agent and Chief Engineer to the Calcutta Electric Supply Corporation, and formerly Chairman of this Local Section has very kindly had data prepared, and I am indebted to him for the following list which he has been so good as to furnish:—

Jute milling ...	19 motors,	aggregating	2,136	b.h.p.
Jute pressing ...	22	"	1,853	"
Flour milling ...	192	"	2,475	"
Printing ...	439	"	1,236	"
Machine shops...	216	"	1,296	"
Pumping ...	236	"	603	"
Lifts	105	"	664	"

These figures afford remarkable evidence of the extensive use that is already made of electric power for industrial purposes in this district. They show that the Calcutta Electric Supply Corporation must have given much attention to the development of this important side of their business, and they also make it clear that many local manufacturers and business men are fully alive to the commercial advantages of electric motive power. I need hardly point out the benefit to the community arising from the avoidance of local smoke and noise, and we must all hope for a rapid extension of the company's operations in this field.

Street lighting by electricity is now becoming a familiar feature in Calcutta and Howrah, as well as in hill stations and elsewhere. Electrical engineering has required for its development a more scientifically trained set of men than in the case of other branches of engineering, and electrical engineers have done much to improve the proper treatment of practical questions of illumination both for outdoor and indoor purposes.

The technical training of engineers in this country has been discussed in various recent papers and reports, and I shall therefore not dwell at length on this matter. I may mention, however, that improvements which had been advocated for years have now been carried out at Sibpur College; one of these is the provision of separate professors of mechanical and electrical engineering, each with an assistant, instead of a single professor for the two subjects; the other is the introduction of a more specialized (and at the same time shorter) course for students taking up these branches. These changes are bound to improve the quality of the men trained by the College. The course is only of "overseer" standard at present, but in the scheme for a Technological Institute at Calcutta proposals have been put forward for the introduction of a higher course for a limited number of students. This scheme is under the consideration of the Government. After the college course practical training in industrial concerns will of course be necessary before the students are of any substantial use. Unfortunately they do not always realize this and are sometimes inclined to expect an initial salary out of all proportion to their utility.

WESTERN LOCAL SECTION: CHAIRMAN'S ADDRESS

By [illegible] Roberts, Member

[illegible]

[illegible]

[illegible]

[illegible]

[illegible] country.

[illegible] is the elaborate and apparently extravagant expenditure on all kinds of labour-saving devices. These exceed anything that is to be found in the latest and best American works, which country I also occasionally visit, and where, [illegible] for the double reason that labour is at a prohibitive price [illegible] continued manual operation is almost impossible. One can only come to the conclusion, therefore, that this extravagance has been dictated, not by the labour conditions of to-day, but by the conditions that are expected to prevail in the early future.

There is every reason to believe that the German capita- [illegible] hension to that day when the labouring classes, so long subdued by dominant militarism, will assert themselves. When competition between our trade and that of the Germans is now considered, this is a factor that must not be forgotten.

A further consideration that must be taken into account is the question of whether the financial condition of that [illegible] ment to subsidize the various trades, distribute bounties, [illegible] is more than probable that this method will have to be considerably curtailed, and that competitive trade, therefore, will be on a fairer footing in this respect.

[illegible] equipped with [illegible]

I [illegible] believe that the bulk of engineers in [illegible] y do not quite realize to what extr [illegible] has been carried in Germany, and wh [illegible] advantage, as it undermines one's individuality, but in the arts of peace this defect does not enter so much into the question.

The Germans, under [illegible] complete equipment. They have also an almost world-wide and effective organization, with which they bring their products to the notice of buyers in every land.

[illegible] treacherous be [illegible] dealing with our present enemy. Before very long the old world rule will be again firmly established, namely that the machine that is going to command the [illegible] requirements, and which gives the all-round best return [illegible]

[illegible] chances in striving for the world's trade, we have many economic advantages in our favour, and in my opinion success is within our reach if we, as a nation, will but stretch out a hand to grasp it.

[illegible] our works in highly efficient order, and filling them with well-trained men.

As bearing out this point, I shall probably not be betraying a secret to many members, when I say that the Council of this Institution, after very careful consideration of this subject from all its aspects, have come to the conclusion, for a number of reasons which need not be entered into here, that practically nothing can be done to assist manufacturers against their foreign competitors, and that the continuance of British trade will mainly depend on economic principles and on the commercial industry and initiative of British manufacturers themselves.

This view, in my opinion, is the only healthy and proper one to take of the position, and if such means are employed I feel certain the country will achieve lasting prosperity, which will be a just recompense for the terrible sacrifice that she is now making.

PROCEEDINGS OF THE INSTITUTION.

ORDINARY MEETING OF 25 FEBRUARY, 1915.

Proceedings of the 576th Ordinary Meeting of The Institution of Electrical Engineers, held on Thursday, 25 February, 1915—Sir JOHN SNELL, President, in the chair.

The minutes of the Ordinary Meeting held on 11 February, 1915, were taken as read, and confirmed.

The PRESIDENT : Before I call upon Mr. Sparks to read his paper, there is one little personal note that I want to strike, because I am sure members will wish to join with me in offering our congratulations to Mrs. Sparks and himself. Not only has he a brother, present with us to-night, who took such an honourable part in the charge of the London Scottish in Flanders and came back wounded, and who, I am glad to say, is now convalescent and looking forward to returning soon to his duties at the front, but Mr. Sparks has also three of his four sons serving the King ; one in the Royal Engineers ; one, who is with us to-night, in the Royal Artillery ; and one, a youngster of only 18½ years, who has so done his duty at the front that not only has he been mentioned in dispatches but he has been awarded by His Majesty the Military Cross. I have only one son and he is serving his King to the best of his ability, but I should feel proud enough of him if I could mention that he had such a record. It must be a source of legitimate pride, both to Mr. Sparks and to his wife, to feel that their sons are doing such splendid work and showing such a splendid example to the young men of this country. I am sure members will join with me in offering our congratulations to them, and ask them, when they write to their son, to convey the good wishes of this Institution, of which the father is such a distinguished member. I ask members to join with me in showing our feelings in this matter by acclamation.

Mr. C. P. SPARKS : It is very difficult for me to find words in which to express the gratitude my wife and I feel for the Resolution that has just been passed. I am indeed proud of my three sons, who, in common with so many hundreds of thousands of British men, are doing their duty to their King and country, and of course I am especially proud of the young fellow who, as Sir John has mentioned, has been awarded the Military Cross.

A paper by Mr. C. P. Sparks, Member, entitled "Electricity applied to Mining" (see page 389), was read and discussed, and the meeting adjourned at 9.55 p.m.

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ELECTRIC COOKING

MAINLY FROM THE CONSUMER'S POINT OF VIEW

By W. R. Cooper, Member.

[illegible]

CONTENTS

[illegible] Records, and diversity factor of the cooking load.

INTRODUCTION.

[illegible] submit the following notes based on personal experience.

So far, in the cooking field, electricity has been chiefly in competition with gas. This competition has therefore [illegible] the gas cooker has proved sufficient to meet the needs of [illegible] require an electric cooker of something like [illegible] hours per week; but in larger houses coal ranges are more usual, because the cooking is more continuous and because hot water is required in large quantities. Naturally the [illegible] range is considerably greater and more profitable than that [illegible] the cooker is larger and partly because the cooking is more extensive. In other words the large cooking consumer, unlike the large lighting consumer, has an appreciably better load factor than the smaller consumer.

CONSUMPTION AND COMPARATIVE COSTS.

In the example to which the author wishes to refer, the number of persons normally in the household is from eight to nine, and there is a good deal of cooking, though not of an elaborate kind. It therefore seemed desirable to put [illegible]

Oven [illegible]	total [illegible] watts
Grill	1,500 "
Two 8-in. hot-plates	[illegible]
One 6-in. hot-plate	750 "

The heat of the grill [illegible] The [illegible] parallel, singly, or in series [illegible] quarter heat respectively, which [illegible]

Personally the author does not look upon the electric heating of domestic water as a proposition that is financially impracticable. It is a question of tariffs. With thermal-storage apparatus a practically continuous [illegible] being supplied, it should be feasible to make a quarterly [illegible] continuous use, at the rate of ½d. per kilowatt-hour. It is difficult, however, to get the station engineer to move in these matters: although willing to supply energy on, say, [illegible] in supplying on a 100 per cent load factor at ½d. per unit. [illegible] degrees F., taking the efficiency at about 80 per cent. This would be enough for many flats; it would be ex- [illegible]

central-station engineers, it was thought best to install a separately-fired coke boiler for supplying the hot water. A No. 10 D "Ideal" domestic boiler by the National Radiator Company was selected, partly because it is provided with a flat top. This form of top is a distinct advantage, because a kettle of hot water can be kept hot indefinitely, or a saucepan can be kept more or less on the simmer, by this means, thus economizing electrical energy to a desirable extent. This boiler, fed with coke, gave an ample supply of hot water—in fact the smaller size might have been used—but the regulation was found to be rather sensitive. This difficulty is most easily overcome by mixing a small proportion of anthracite (say one-fifth by volume) with the coke.

To estimate the consumption of energy for a given household is not an easy matter owing to the great variations that are found in the mode of living. It is sometimes stated that 1 kilowatt-hour per person per day may be taken as an average figure. Where the cooking is reduced to a minimum (for example, by having a hot midday meal and reducing the cooking as far as possible for other meals) this may be sufficient; but it seems to be quite inadequate in other cases. Probably 1½ kilowatt-hours per person may be said to be low where late dinner is the rule. In the present instance the average consumption was found to be about 2 kilowatt-hours per person per day in the winter-time and about 1·6 in the summer. This figure was obtained with a cook who might be described as "careful." Naturally the number of kilowatt-hours per person diminishes as the household increases, and it need scarcely be said that it would be considerably greater in houses where the cooking is elaborate and where waste is of no account.

The consumption per week was approximately 110 kilowatt-hours in the winter-time and, say, 90 kilowatt-hours in the summer. The actual figures over particular periods were as follows :—

TABLE 1.—*Average Consumption of Electrical Energy per week.*

Month	Period Observed	Kw.-hours	Month	Period Observed	Kw.-hours
February	3 weeks	113	August	3 weeks	92
March	4 ,,	99	September	2 ,,	95
April	3 ,,	110	October	3 ,,	104
May	4 ,,	98	November	2 ,,	110
June	3 ,,	107	December	4 ,,	115
July	3 ,,	85	January	4 ,,	112

Before electric cooking was adopted, the average annual cost (based on the two preceding years) with coal was as follows :—

	£	s.	d.
Electrical energy for light and other purposes	9	0	0
Meters	1	0	0
Coal	13	10	0
	£23	10	0

With electric cooking the result for the year was as follows :—

	£	s.	d.
Electrical energy for light, etc., as above	2	16	3
Electrical energy for cooking (including fixed charge) 5,024 kw.-hours (average price 1·04d. per kw.-hour)	21	19	0
Meters	1	0	0
Coke and coal	6	13	6
	£32	8	9

In the above no credit has been allowed for certain advantages of the electrical system. The number of kilowatt-hours for lighting and other uses has been taken to be the same in both cases, and a correction has been introduced for a short period of defective meter working. The net result is seen to be an increase in cost of £8 18s. 9d. per annum over the cost of cooking with coal.

OUTLAY.

The initial outlay was as follows :—

	£	s.	d.
Electric cooker	23	15	6
Cooking utensils	2	5	0
Wiring for supply to cooker	9	4	5
Boiler and connecting up same ...	10	6	4
	£45	11	3

Later, a porringer taking 800 watts and having three heats was added, which, with wiring, cost £4. This was found to be a great convenience. It should be noted that the above prices for apparatus are list prices.

In the above outlay the cost of the cooker seems high, but the price of this part of the equipment will certainly fall as the quantities manufactured become greater. Moreover there are many cookers on the market of lower price than the above. On the other hand, the cost of wiring is undoubtedly a heavy proportion of the whole. In this particular instance the cost was increased by an additional switch; but, even so, the cost of such work must inevitably remain high so long as engineers adhere to the fashion of using screwed tubing. Of course there is the idea that the steel tube is good from the point of view of earthing. Actually, however, when the switch and meter are taken into consideration, the tubing is in most cases of little value for this purpose and a special earthing wire must be used. That being so, wood casing might be employed equally well. From the point of view of cheapness the author sees no reason why armoured cable should not be used without further protection. As a rule, the kitchen and its surroundings have no architectural beauty, and armoured cable neatly fixed to the wall would not look unsightly (indeed it would be less noticeable than hot-water pipes) and it could be fixed with a minimum of labour. A householder often does not mind spending a lump sum on an equipment like a cooker, but he is chary of spending much on what seems to him to be useless extras.

Some consumers have the good fortune to live in districts where the electrical part of the equipment can be hired. The author was not in this happy position. In his opinion, hiring powers for local authorities are essential if electric cooking is to make the progress it merits.

From the point of view of cleanliness it is no doubt best to place the boiler in the back kitchen. On the other hand, it may be wished to use the heat given off by the boiler and

[illegible] nature of a by-product method.

[illegible] and repetition of results, and the great con[illegible]

[illegible]

[illegible] is on or off. She should be trained to cut the supply off at this main switch in addition to the subsidiary switches. Some cookers are provided with a pilot lamp under a small red window fitted to the casing of the cooker itself. This, however, is scarcely sufficient to attract attention. An [illegible]

Whether it is desirable to carry the principle further and have a pilot light for each part of the equipment is open to question. Personally, provided the switches are well illuminated, the author does not think it is desirable to go to this complication, which, moreover, necessarily pro[illegible] On the other hand, he feels that it is most important to [illegible] not only [illegible] tainable at a glance, but also so placed that they are easily operated. For this reason it is very undesirable to mount them, as is sometimes done, on the side of the cooker, because the cook will certainly avoid bending down to look at the side of the oven; moreover, such switches will often be badly illuminated. If they are mounted on [illegible] position, like a table switchboard; but this position may lead to the difficulty that the switches so placed are rather exposed to liquids spilt during cooking. Notwithstanding [illegible] bined and complete unit, the author is inclined to think that switches are best placed on the wall behind the cooker, somewhat to one side, on the principle that the [illegible]

As regards fuses, practice is at present divided between

[illegible] the thermometer, stated more than once that sufficient heat was not obtainable, and on one occasion said that the time required for heating up was 25 minutes, w[illegible] nation the thermometer was found to b[illegible] [illegible] meter is used.

[illegible] on at full heat for a certain time, say 10 or 15 minutes, and [illegible] the oven is to be used merely for single joints or other single items, but even with th[illegible] several things in the oven at the same time, and if no thermometer is provided she must fall back on the hand test to know whether the temperature is what it should be after the oven door has been opened half-a-dozen times.

There has been much talk from time to time of the saving that is effected in meat by electric cooking. It has been freely stated, for instance, that the loss in weight with coal [illegible] cent with electric cooking. Actually, it is impossible to give a fixed figure. If there is much fat the loss will be heavy, whereas if the joint is lean the loss will be much less. Therefore only an average figure can be obtained, from which the variations may be large. Further, the actual figure obtained, judging by the author's experience, [illegible] extent. This, then, is another good reason for having the oven fitted with a thermometer.

The figures in Tables 2 and 3, which the author obtained [illegible] of weight, may be of interest.

[illegible] perhaps, 50 degrees F. higher than in those cases where the loss was low. This, the author thinks, is sufficient evidence [illegible] obtained without it. With it the results are excellent.

Of course, the loss of weight will vary with the type of joint. Only one type of joint is referred to above, as it [illegible]

were selected as being free from an indefinite amount of bone; incidentally the loss should be rather high on that account. The usual rule for the time required (namely 20 minutes plus 20 minutes per pound) was adopted. Apart from loss of weight, there is sometimes a gain in electric cooking through less basting, and the resulting dripping is in a more usable condition. It need scarcely be remarked that the present paper refers only to private houses; restaurants are another matter.

TABLE 2.—*Loss when Cooking by Coal.*

Character of Joint	Original Weight	Loss	Remarks
	lb. oz.		
(1) Rolled ribs of beef	4 7	29½ %	
(2) ,, ,,	4 2	29 %	—
(3) ,, ,,	3 13	18½ %	Rather lean
(4) ,, ,,	4 0	23 %	—
Average ...	...	25 %	—

TABLE 3.—*Loss when Cooking by Electricity.*

Character of Joint	Original Weight	Loss	Remarks
Normal Temperature.			
	lb. oz.		
(1) Rolled ribs of beef	3 14	13 %	—
(2) ,, ,,	3 8	14½ %	—
(3) ,, ,,	3 13	13 %	Joint lean and rather underdone
(4) ,, ,,	4 1	20 %	Joint rather fat
(5) ,, ,,	4 1	12½ %	—
(6) ,, ,,	4 12	14½ %	Joint rather fat
(7) ,, ,,	4 0	14½ %	—
Average ...	...	14½ %	—
Temperature too high.			
(8) Rolled ribs of beef	4 0	23½ %	—
(9) ,, ,,	4 4	23½ %	
(10) ,, ,,	4 10	23½ %	
(11) ,, ,,	4 2	24 %	Joint very fat
Average ...	...	23½ %	—

Extravagant claims in this, as in any other direction, are to be deprecated. For example, in a technical article not so very long ago it was stated that even "if gas were provided free of cost it would still be far cheaper to cook by electricity" on account of the saving in the meat. Such a statement is absurd. Joints are not cooked every day. Assuming two a week there might be a saving of, say, a pound of meat, or, say, 1s. per week in the case here considered, whereas the electricity bill is much greater than this figure. It is forgotten that the roasting of joints is but a small part of the total cooking. Such claims can only do harm to a good cause.

It is sometimes objected that the readings of a thermometer fitted to the oven door are not indications of the real temperature within the oven and therefore the thermometer is undesirable. No doubt the indications are far from accurate; but they are nevertheless of value, because one can find by trial without much difficulty what readings correspond to suitable temperatures. In the present instance the author found that a suitable routine, in the case of joints, is first to raise the temperature to 350° F.; the joint is then put in, the temperature is allowed to fall to 250° F. by switching off, and is kept (by switching on the low heat occasionally) between 250° F. and 300° F. This is not in accordance with published directions as to temperatures for cooking, but it may be regarded as the calibration of this particular oven.

The energy required to heat an oven is not as great as might be expected. In the present case the oven, with an input of 3 kilowatts, reaches a temperature of 250° F. in 5 minutes, *i.e.* by the expenditure of 0·25 kilowatt-hour. Even so it is preferable to avoid the use of the oven for small operations, such as keeping dishes hot, if it is not already in use. For this purpose the author has found it convenient to use what may be described as a small portable oven. It consists simply of a hood of tin plate, preferably double, as shown in Fig. 1, which can be

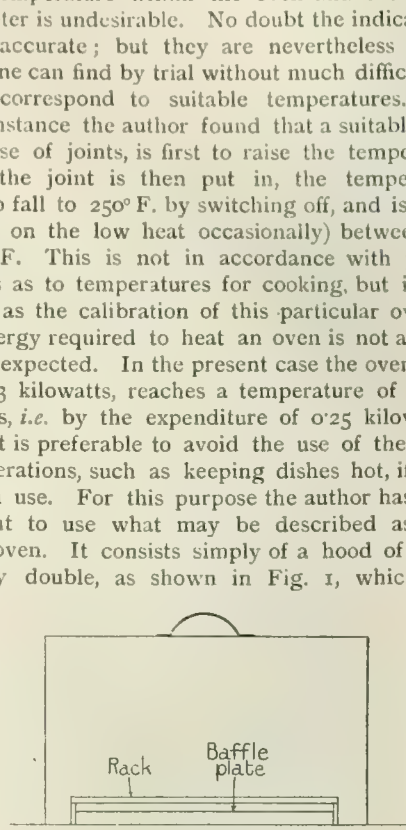


FIG. 1.—"Portable" Oven.

placed over any hot-plate as a heating element. It is provided with a low metal stand and deflecting plate so that the heat is not excessive near the hot-plate; or an asbestos sheet may be used to give protection. As a rule, a hot-plate has already been in use, and can then be conveniently employed for heating this oven with or without current, depending on the temperature desired.

It is desirable that an oven should heat up rapidly, partly because this is more convenient and partly because it is more economical. Thus the heating elements should be so made that they become effective as soon as possible after they are switched on. Moreover, an ample input is desirable, because it is cheaper to have, say, 3 kilowatts on for 10 minutes than 2 kilowatts for 20 minutes. In other words the heating up should take place so rapidly that the heat losses have not much time to take effect, after which the input can be reduced simply to supply these losses. For these reasons the time taken to reach a temperature of 300° F. should not exceed 10 minutes.

Similarly, hot-plates should heat up rapidly.

SOME POINTS IN DESIGN.

The points in design to which the author wishes to refer are chiefly concerned with safety.

As engineers we sometimes fail to realize how dangerous the layman may render a piece of apparatus which to the engineer seems perfectly safe. Take, for example, the

ordinary wall-plug. It seems safe enough. Yet others like the author himself, have probably seen it grasped in such a way that the fingers come on to the pins as the plug is withdrawn. If a cook withdraws a plug in this way the operation is accompanied by words which do not proclaim the advantages of electric cooking, and thereafter the cook may feel shy about handling such devices. It may be objected that plugs should be unnecessary in the kitchen. Accessory apparatus is, however, often desired and then a plug would be inevitable, and in any case plugs are required for radiators. Plugs are sometimes provided with shields, which give some protection. The author thinks, however, that it would be more satisfactory to fit a metal ring round the socket (as

FIG. 2.—Protection of Sockets.

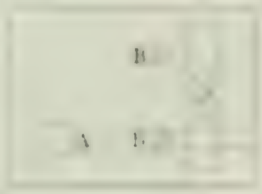


FIG. 3.—Socket with Exposed Terminals.

in Fig. 2) so that the pins are not exposed so long as they are alive. This ring should preferably be earthed. Another method is to interlock the plug with a switch but this cannot well be done where different heats are required. A new type of plug giving the desired protection has recently been placed on the market, but the ordinary plug with metal shield or metallic sleeve is not readily obtainable, apparently because the average wiring contractor is unwilling to pay the price. Another point is that the live metal of the socket for the reception of the pins of the plug is often brought nearer to the surface than is necessary, and can be touched by persons when cleaning.

FIG. 4.—Socket with Spiral.

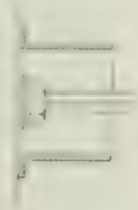


FIG. 5.—Protection of Pins by Housing.

It is noticeable that live metal is exposed somewhat heedlessly at times. As an example we may take the socket illustrated in Fig. 3. In many ways it is excellent and is used considerably on flat-irons and similar apparatus. The body consists of porcelain, in which the brass sleeves A are held by screws B; the latter clamp the flexible wire and at the same time hold the sleeves in position, but the holes are not closed, and thus live metal is exposed. The author is not aware that any trouble has arisen from this arrangement so far, but he doubts if terminals of opposite polarity would be exposed about an inch apart in any other branch of electrical work.

A similar arrangement is shown in Fig. 4, the socket being for a single terminal. Here the flexible is protected with a spiral to prevent the flexible from breaking by continued bending. The objection to this arrangement is that if the flexible becomes frayed in the neighbourhood of the spiral and the latter touching the conductor (which is quite liable to happen, particularly when the stripped end of the flexible is put in [illegible]) [illegible]. This may not much matter when portable apparatus is used on, say, a dining-room table, but it is much more serious if such apparatus is used in the neighbourhood of earthed metal-work. For this reason it is suggested that there should be discrimination between apparatus [illegible] and that which may not be used in the kitchen.

In portable sockets the pins are often exposed so that live metal is exposed when the socket is in position, at least if it is not pushed home. It is desirable that these pins should be housed, as indicated in Fig. 5.

One of the troubles with flexible wire is the breaking [illegible] being continually subjected to bending. This may seem a small matter to the engineer, who can put the matter right in a few minutes; but to the layman it is annoying, for he cannot put the matter right without calling in assistance—which means delay and a bad advertisement for electrical methods. In what follows reference is made to flexible wires for portable apparatus, such as electric irons, kettles, etc. (not for kitchen apparatus for which some type of armoured conductor would be used).

It becomes evident that many of the usual twisted flexible cords are unsuitable for this class of work, and that special types should be used. These are now becoming available. In seeking to meet this need, cable-makers seem to be following two opposed methods. The first is to make the flexible wire so that it bends very easily and will therefore adapt itself. The second is to make the flexible wire rather stiffer, so that any bend will be less sharp. The author is inclined to think that the latter is the better alternative because the breaking of the copper strands depends on the sharpness of the bend.

In order to test the suitability of flexible wires for this class of work the author has recently subjected a number of samples to a bending test. The machine for applying this test is shown diagrammatically in Fig. 6. In this arrangement a loop of the flexible wire A under test is clamped to a board B by a clamp C, and the board is made to oscillate on knife edges, D, which form a continuation of the edge of the board where the flexible wire is clamped. To the loop is suspended a weight, E, of 1 lb., and the suspending wire is carried between guides, F, so as to prevent swinging of the weight. The board is connected by a rod to a crank, G, the wheel of which is driven by a small motor. The wheel is fitted with a counter. By this means the board is given an oscillating movement [illegible] and the flexible is bent first in one direction and then in the other. In this way eight samples were tested at a time.

The circuit to the motor is carried through all the flexible [illegible]

the cores of any flexible wire fails at either end of the sample. It would no doubt be better to have the oscillation through 180°, but a larger angle than 85° could not be obtained without using more complicated apparatus. It is evident from the results here given that the smaller angle prolongs the test unnecessarily.

Since the edges of the board B and the clamps C are on the same level when the former is vertical, the same part of the flexible is subjected to bending whichever way the board is inclined to the vertical. With a perfectly flexible cord there would be no vertical movement of the weight, but the stiffer the cord the greater the movement. It seemed desirable to have some measure of the flexibility, and for this purpose a length of each cord was allowed to hang over a right-angle corner to the extent of 18 inches with a weight of 4 oz. attached to it, and the deflection from the vertical at a depth of 18 inches was taken as a measure of the inflexibility. This is indicated in Fig. 7, in which *a* is the deflection measured. From being coiled up, cord is liable to have a certain set imparted to it, and electrically, lasted infinitely better than No. 2, notwithstanding the rather greater flexibility of the latter. It seemed possible that this result might be explained by some difference in the mechanical qualities of the copper, and therefore lengths of Nos. 2 and 3 were taken, the conductor was carefully freed from insulation and the conductor of 70/40 S.W.G. in each case was tested with 4 oz. (a previous trial showed 8 oz. to be too much). The results are given at the end of the table (Samples 8 and 9), but show very little difference, there being a small advantage in favour of the conductor of No. 2, the weaker flexible cord. Again, the more robust flexible, No. 4, which was supplied for use with an electric iron, did not test out so well as No. 3.

As often happens in such tests, the results are rather contradictory. Thus, Sample 5 had been found by the author to be unsatisfactory in actual use, yet it tested up quite well. This may be due to want of uniformity in the flexible wire, which is noticeable in many of the tests. For example, one end of Sample 5 lasted much longer than the

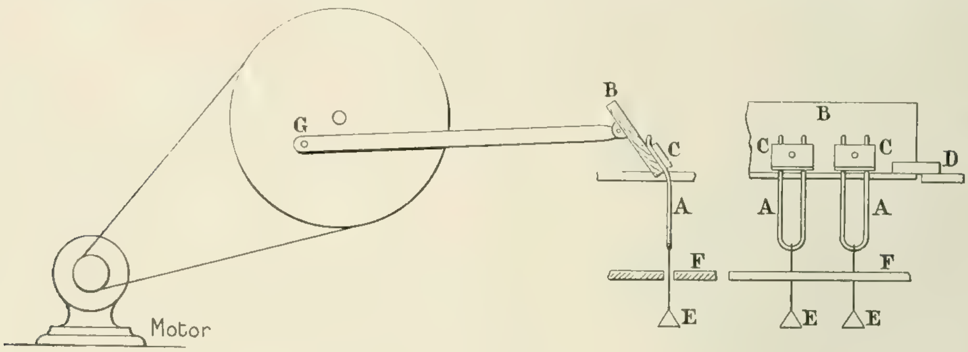


FIG. 6.—Arrangement for Testing Flexibles.

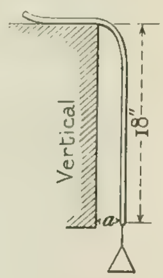


FIG. 7.—Flexibility Test.

therefore two measurements were taken—one in the sense of the set and one contrary to it—and the mean was regarded as a measure of the inflexibility.

The load on the flexible was originally made 8 oz. (or 4 oz. per side) but after running for 75,000 complete bends (*i.e.* backwards and forwards) without a failure, the weight was increased to 1 lb. (or 8 oz. per side of loop) to hasten the process. Thus all the figures are not quite comparable. The weight of 1 lb. was changed to 8 oz. when either side of a sample had completely failed. The results obtained are shown in Tables 4 and 5, the former referring to ordinary flexible wires and the latter to flexible wires specially made for portable apparatus. The flexible wires are given in the order of total cross-section of conductor and the cores are numbered 1, 2, 3, 4; Nos. 1 and 2 being together at one end of the sample, and Nos. 3 and 4 at the other end. By "maximum diameter" is meant the diameter of the hole through which the flexible will pass.

From the user's point of view, both the diameter and the inflexibility should be small. Referring to Table 4 (ordinary flexible wires), sample No. 1 was smaller in the conductor than would generally be used. Samples 2 and 3 are similar in general character, and it is rather remarkable that No. 2, which should be stronger, lasted a shorter time than No. 1; also No. 3, which appeared to be inferior other end. This particular sample was taken from flexible wire which had been in use for about 10 months, but the part selected had not been subjected to hard treatment.

Sample 6 is ordinary "Association" flexible wire by a well-known maker. Except for one of the four possible breaks, this gave a remarkably long life.

Workshop flexible wire (No. 7) lasts well—in fact better than an armoured type (No. 17)—but is too inflexible to be convenient.

With regard to the special flexible wires shown in Table 5, these have mostly larger conductors than the ordinary flexible wires; and they have larger overall diameter and less flexibility. Many are circular. Although the circular type has the advantage of better shape for mechanical wear, from the electrical point of view this form has the disadvantage that if one conductor fails there is greater chance of a short-circuit to the other conductor than with twisted twin conductors. This accounts for the lack of detail in some of the tests (*e.g.* No. 13). It will be noticed that Nos. 11 and 13 did not give such long tests as some of the ordinary flexible wires. The larger flexible wires (such as Nos. 14, 15, and 16) are scarcely comparable with the others, being much larger. No. 17 appeared to fail through failure of the wire braiding, which thus allowed more severe bending at this particular point. In the case of Sample 18, the length supplied was too small to form a

[illegible] the wire. [illegible] Sample [illegible] as a flexible wire [illegible] ordinary [illegible] [illegible] [illegible]

[illegible]

No.	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]
			[illegible]	[illegible]			
1	Unknown	Twisted twin. Each conductor [illegible] rubber and silk braiding	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] with [illegible]
2	[illegible]	Twisted twin. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	Twisted twin. Each conductor covered with one lapping of cotton, then vulcanized rubber and silk braiding. Insulation easily removable	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] „ 4—331 with [illegible]
4	[illegible]	Twisted twin. Supplied for use with electric iron. Each conductor covered with one lapping of cotton, then with vulcanized rubber and cotton braiding	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	Twisted twin. Supplied for use with electric iron. Unsatisfactory. Tested after about 10 months use. Each conductor covered with one lapping of cotton, then three lappings of pure rubber, a lapping of cotton and cotton braiding	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	A	Twisted twin. Each conductor covered with one lapping of cotton, then two lappings of pure rubber, two lappings of cotton and silk braiding	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	B	Circular "workshop." Each conductor covered with one lapping of cotton, then pure rubber and vulcanized rubber. The two cores twisted together, made up with wormings, braided and compounded	40/36	[illegible]	[illegible]	Too inflexible for [illegible]	[illegible] with 8 oz.
8	Unknown	Copper conductor of No. 2	[illegible]	—	—	—	Right [illegible] Left [illegible] Average [illegible]
9	[illegible]	Copper conductor of No. 3	70/40	—	—	—	Right [illegible] Left [illegible] Average [illegible]

not so good as the ordinary flexible wire No. 6 of Table 4. On the other hand, if so great flexibility is not required and yet a reasonable size, the construction of Sample 1 is [illegible] a type that is desirable for electric radiators.

[illegible] flexible wire suitable for portable appara[illegible] breaking.

[illegible]

TABLE 5.—TESTS OF FLEXIBLE WIRES. *Special Flexible Wires.*

No.	Maker	Description	Conductors: No. and Gauge	Conductors: Total Cross-section of Copper (Sq. in. × 1,000)	Max. Diameter in mm.	Inflexibility (Deflection in mm.)	No. of Complete Bends for Failure (in Thousands)
10	C	Circular twin. Each conductor covered with a spiral layer of paper, then one layer of pure rubber and two layers of vulcanized rubber. The two cores laid up circular with cotton wormings, then braided with glacé cotton and finally armoured with a spiral segmental brass wire	34/40	0·61	7	52	No failure up to 995 with 8 oz. *Plus* 75 with 4 oz.
11	A	Twisted twin. Each conductor consists of three 8-mil tinned steel, round each of which are twisted six No. 36 tinned copper wires, the whole spiraled together. Each conductor covered with one lapping of cotton, then vulcanized rubber, one lapping of worsted and glacé braiding	18/36 copper + 3/0·008″ steel	0·82	6	18	No. 1— 8·0, „ 2—40·3 (with 8 oz.); „ 3—45·2, „ 4—45·5 (*Plus* 75 with 4 oz.)
12	Unknown	Twisted twin. Similar to No. 11	18/36 copper + 3/0·008″ steel	0·82	6	18	No. 1—125, „ 2—169, „ 3— 88, „ 4—104 with 8 oz.
13	A	Circular twin. Conductor similar to No. 11. Each conductor covered with one lapping of cotton and vulcanized rubber. The two cores laid up circular with worsted wormings, then worsted braided and glacé braided	18/36 copper + 3/0·008″ steel	0·82	6	23	Total failure at about 192 with 8 oz. *Plus* 75 with 4 oz.
14	E	Twisted twin. Conductors of braided tinned copper wires. Each conductor covered with special vulcanized rubber, then braided with strong black twine	48/38	1·07	11	17	No. 1—458, „ 2—506 (with 8 oz.); „ 3—276, „ 4—306 (*Plus* 75 with 4 oz.)
15	E	Circular twin. Each conductor, as in No. 5, covered with special vulcanized rubber; the two cores then twisted together, wormed circular with cotton and braided with strong black twine	48/38	1·07	10	34	No failure up to 995 with 8 oz. *Plus* 75 with 4 oz.
16	E	Circular twin. Same as No. 15, except that cotton wormings are cotton braided and braided overall with hard white cord	48/38	1·07	11	50	No failure up to 995 with 8 oz. *Plus* 75 with 4 oz.
17	G	Circular twin. Each conductor covered with one lapping of cotton, then pure rubber and a lapping of cotton. The two cores twisted together, made circular with wormings, braided and compounded. Braided overall with tinned steel wire	25/36	1·13	7	Too inflexible for measurement	One end—258 with 8 oz.
18	D	Circular twin. Conductors of tinned copper. Each conductor covered with a lapping of pure rubber, and then vulcanized rubber. The two cores twisted together and made circular with vulcanized rubber	11/30	1·33	$9\frac{1}{2}$	Too inflexible for measurement	One end—about 33, Other end—85 with 8 oz.
19	F	Twisted twin. Each conductor of tinned copper covered with pure rubber, then with vulcanized rubber and cotton braiding. Twisted together with a dummy supporting cord made up of a cotton core with braided covering	40/36	1·81	6	23	No. 1—271, „ 2—319 (with 8 oz.); „ 3—110, „ 4—110 (*Plus* 75 with 4 oz.)

are sometimes fitted, but metal for this purpose is not very desirable, as generally painted iron, and probably a thin insulated case of ebonite for protecting the apparatus cover and not preventing sharp bends would prove equally effective.

It is bad to encourage things to use long lengths of flexible cable lying about the floors of houses for supplying radiators. In course of time this flexible cable must wear and eventually develop a fault. As a rule radiators are fitted with switches controlling all the heating elements, the result being that the flexible wire is left permanently alive. In the Institution Wiring Rules it is recommended that radiators should be made so that they can only be partially controlled in this way, but no heed is generally paid to this very desirable rule. This is due to the wrong idea that convenience should take precedence of safety.

Earthing

It is generally recognized, though perhaps rather vaguely, that electric cookers should be earthed so as to ensure immunity from shock. Unfortunately there is no authority having the power to enforce such earthing. Possibly in those cases where the supply undertaking has a wiring department this part of the work receives proper attention; but in many cases the wiring is carried out by contractors even if the apparatus is obtained on hire from the municipality. It seems that some supply authorities consider that the wiring is not a matter about which they need concern themselves, the result being that no earth connection is put in until the cook begins to complain of shocks. This is obviously a very wrong procedure. The station engineer should make himself responsible for the earthing; moreover, he should go further and see that it has been carried out effectively.

It is to be feared that in many cases such earthing as has been put in is not really effective. For example, a wire is run to the iron case of the main fuses and clamped under a screw. This may or may not be effective, or it may give an intermittent earth. There is no question that the earthing should be to a water pipe, and that the effectiveness of the earthing should be tested. Moreover, the earthing that is put in is often of the flimsiest character, and will probably one day be removed by the householder or decorator, as being due, in their opinion, to some foolish mistake. Earthing clips and wires should be more substantial than is generally the case. Further, the author feels it would be an advantage if such clips carried a red metal label bearing the words "Earth Connection—Must Not Be Removed."

As to testing, probably the simplest method is to apply the pressure of the main to the surface of the cooker through a fairly high candle-power carbon lamp (say 32 c.p.). If the lamp glows as brightly as when placed across the mains, the earthing is satisfactory. This, however, only holds good if one side of the system is earthed, and it is rather rough. It would be better to allow a current of, say, 5 amperes to flow through a resistance to earth via the earthed cooker and to note the voltage across the resistance. The voltage, if the earth connection is good, would have the normal value.

Care must also be exercised with accessory apparatus (such as lamp-plates) alongside the earthed cooker. Apparently it is not always realized that the mixing of earthed and unearthed apparatus in the way is much more dangerous than the absence of earthing altogether. Obviously, if the cook puts her hands simultaneously upon the earthed cooker and upon unearthed apparatus which has developed an earth, she may receive a very severe shock.

From that point of view there should be careful discrimination between apparatus which may be used in the kitchen and that which may only be used in other parts of the house and in conjunction with the cooker. For example, on the dining room table a fault in the case of a kettle is of little importance as regards shock, but it is otherwise in the kitchen. For this reason the present form of wall plug should not be permitted in the kitchen; three pin plugs with earthed connection should be used, and leads should be of flexible metal tubing, the socket, tubing and plug being properly connected together. Similarly, tumbler switches with metal covers should not be permitted on cooking apparatus except with an earthed connection.

If the author might make a suggestion it would be that the Council of the Institution should draw up rules as to earthing: the proper methods to be adopted, and tests to be applied. And further, that they should go so far as to discriminate between apparatus that should, and that should not, be used in the kitchen, and should recommend the character of flexible cords to be used for radiators and similar apparatus. No hardship need be inflicted. The author feels that if some such step is not taken and pressed home vigorously, electric cooking will suffer materially in the same way as electricity in mining has suffered through want of earthed control. Proper material and apparatus is available, but control is necessary. The Institution could effect this control through the station engineers, who, as members of the Institution, should be willing to co-operate.

At the same time the standardization of socket connections on electric irons and similar apparatus might be considered. Manufacturers would realize that there is nothing to be gained by every manufacturer having his own size and spacing of pins. To the user it is exasperating to have to buy a particular socket connection for a particular piece of apparatus.

Tariffs and Maintenance

Although the author does not wish to enter into a detailed discussion of this well-worn subject of tariffs, there are two points which have impressed him as a consumer. The first point refers to what is generally known as the "primary charge." Occasionally the consumer is fortunate enough to have the offer of a very low flat rate. More generally, however, the tariff involves a primary charge which may depend on the rateable value of the house or upon the amount of lighting and plant installed, and, further, a secondary charge of so much per kilowatt-hour consumed. The main objection to the rateable value basis is that there is no true relation between assessment and the amount consumed, and it is not applicable to very many outlying districts. Nevertheless, if the system becomes sufficiently popular to give satisfaction such consumers will find its value. It is desirable, however, to look at the fish which we do not succeed in attracting as well as at that which is brought within the net—indeed, the former

is much the more important. As a possible consumer the author objects to paying a heavy primary charge when he may be using only a cooker. In comparing the cost of electric cooking with coal cooking this heavy charge may be sufficient to deter him from making the experiment with a system of which, as a householder, he has no first-hand experience. That is the attitude that must be borne in mind.

The station engineer may reply :—

(1) That the primary charge takes care of the maximum demand (fixed charges) of the lighting ; or
(2) That the primary charge takes care also of the maximum demand of the heating and cooking.
(3) That water is supplied on an assessment basis ; or
(4) That a man who has a high assessment deserves to pay more for his commodities than other men.

That the primary charge provides for the fixed charges of generation for the lighting load is a fair basis on which to go. In that case it should bear some relation to the maximum lighting load. During the last few years many station engineers have complained that the lighting load was much reduced through the use of metal-filament lamps; yet there seems to be no tendency for the percentage charged on the rateable value to be reduced. For example, at Norwich the charge is 12 per cent, the same as it was six years ago.

That the primary charge provides for the fixed charges of generation for the heating and cooking load as well as for the lighting load is obviously fallacious if reliance is placed on a fixed percentage. If, say, 12 per cent is correct for a single cooker, it cannot be also correct for a cooker plus half-a-dozen radiators.

That water is supplied on an assessment basis for domestic purposes is a poor argument, because this supply does not carry with it any secondary charge.

That a man who has a high assessment deserves to pay more for his commodities than other men is a contention more worthy of a highwayman than a civilized engineer. It is sometimes said that the prices of other commodities vary with the assessment. This, however, is a confusion of ideas. Prices vary with the locality, but if A and B live side by side in houses of different rateable values, the tradesman does not adjust his prices accordingly in serving these two customers.

If the assessment basis is found to be generally expedient then the author would suggest that the rateable value should be treated as an elastic quantity, subject to the discretion of the engineer. It is obviously absurd that a consumer should be made to pay a larger primary charge than is necessary simply because he has a garden. It is not business. The engineer should remember that a high assessment probably carries a higher load factor with it, and he should therefore try to meet the consumer as far as possible on the primary charge.

The author thinks it would be an excellent thing if all station engineers were compelled to employ electric cooking exclusively in their homes and also to pay for the energy so consumed. This would not only familiarize them with the apparatus, but would show them the defects of some of the tariffs that they try to inflict on other people. The engineer should at least try the medicine that he himself prescribes.

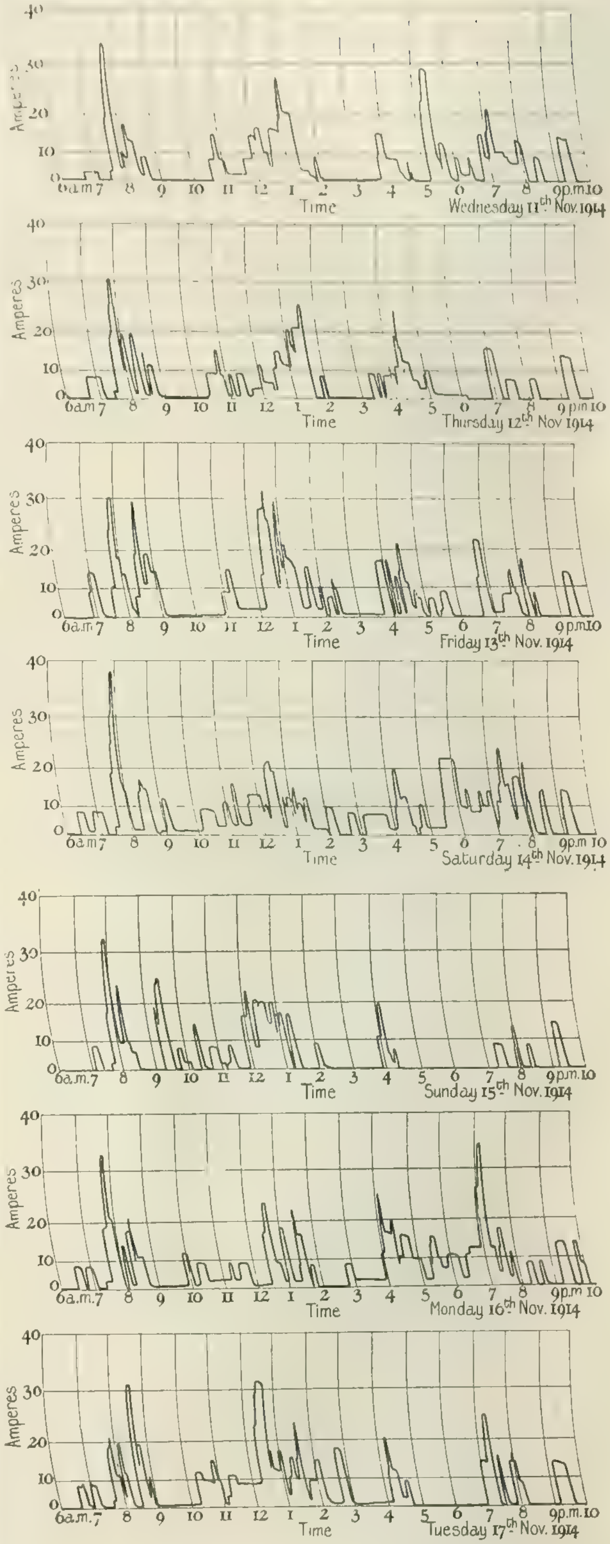


Fig. 8.—A Week's Record of Cooking.

The second point that has impressed the author is the

[illegible] achievement.

Although not closely connected with tariffs, perhaps a word may be said here on the subject of maintenance. In such a subject as electric cooking, considering but short experience, it may be a little difficult to form an accurate opinion on the part of maintenance. In the case of the council to which reference has been made, over a period of 12 months [illegible]. The author is inclined to think that the hotplate is the most vulnerable part of an equipment. But whatever the cost may ultimately be, maintenance is a subject of vital importance to the consumer. If, say, a hot-plate or an oven goes wrong, the consumer does not like to be kept a week or more for the repair to be made. Moreover, he would like to know quite definitely how much the maintenance is going to cost him per annum. It seems to the author that in a question which is of equal importance to the station engineer and to the manufacturer there should be co-operation between the two. The manufacturer should be prepared to quote a reasonable figure for maintenance. It may very possibly cost him more than this amount, but he is still gaining experience and he should be prepared to pay for it. The station engineer on his part is anxious to keep the consumer satisfied. He should therefore be prepared to carry out the maintenance on behalf of the manufacturer at practically cost price; but the manufacturer should not expect more than this. It is obviously much easier for the station engineer to carry out these minor repairs than for the manufacturer or his agent to do so, and such an arrangement could be made without the engineer being bound to any particular type of apparatus. The author believes that some small move has already been made in this direction, but by no means adequately.

Diversity Factor.

There are still some station engineers who think that the diversity factor of a cooking load is not high. On the other hand, it is sometimes stated that the diversity factor is as high as 20. This figure, however, is based on the maximum possible load of the apparatus. It is therefore not the true diversity factor, and is liable to cause confusion. In small apparatus it may, perhaps, be correct to take the maximum possible as being equal to the consumer's maximum demand, but in larger types it would seem more reasonable to take the consumer's maximum as being about 75 per cent of the maximum possible. This is supported by the records given later. Thus the figure of 20 would drop to 15, which means that the load factor of the individual consumer is under 7 per cent.

In the case referred to at the beginning of this paper [illegible] diversity factor cannot [illegible]

The above remarks are supported by curves which the author has taken and which are reproduced in Fig. 8. It is evident from these that the load is of a desirable kind, for it is well distributed throughout the day. Apart from this, two things are noticeable. The first is that the consumption in any part of the day varies considerably. For example, if the meter readings are noted three times a day at regular hours it is found

Fig. 9.—Composite curve of Records in Fig. 8.

that the amount consumed in any one of those intervals varies considerably from day to day. The second point is that the character of the load varies from day to day. Consequently the combined loads of, say, half-a-dozen consumers of this precise type would give a much better curve than any of the curves in Fig. 8 [illegible] may be gained by combining the curves for one week. This has been done approximately in Fig. 9, which is the composite or average curve of those in Fig. 8 based on 10-minute plottings. It is, of course, only roughly correct, but it shows clearly the individual diversity of consumers having the same daily time-table. Actually the diversity [illegible]

When, in addition, we remember the diversity of different classes of consumers it becomes evident that the cooking load is one that is very desirable. Further, there is the important point that the lighting peak and the [illegible]

[illegible]

Conclusion.

Briefly it may be said that electric cooking appeals to the consumer because it gives better results than with other methods, and it may do not a little towards the solution of what is known as the "servant problem." Equally it should appeal to the station engineer because—

(1) The combination of high diversity factor and fairly good individual load factor gives a high load factor on the mains.

(2) It is a load which falls off very little in the summer time.

(3) On present tariffs the consumer can do more with electric cooking than with electric heating for a given annual expenditure.

In conclusion the author would express the hope that these notes may induce station engineers to pay more attention to cultivating the cooking load in general and the larger class of cooking consumer in particular. Electric cooking, as a load, should be a valuable asset to the central-station engineer, and any criticisms that the author has here made are merely put forward in the desire to make a good thing still better.

Discussion before The Institution, 11 March, 1915.

Mr. Wilkinson

Mr. G. Wilkinson: The first matter I should like to mention in connection with the paper is its title. I do not know that the members of this Institution are particularly well qualified for discussing the paper from the consumer's point of view. On the first page the author mentions electric water heating and makes a timely reference to the question of tariffs. I suggest that central-station engineers have been rather too careful on this matter of tariffs. A commercial man who is endeavouring to place a new commodity upon the market does not say to himself: How much will this cost me to make per gross? and fix his selling price accordingly. He is quite ready to sell for the first 12 months with little if any profit, and possibly at a loss. He will assess his probable sales in the course of two or three years' time, and will then fix his prices upon that basis at the outset, standing the risk in the interim. Supply-station engineers have frequently made a mistake in fixing tariffs for a new application of electrical energy upon their costs of production at the moment. Instead of that they ought to take a survey of their supply area, form an opinion as to the growth that will take place in the course of two or three years due to the introduction of the new line of business, and if they find there is a likelihood of increasing their output by, say, half a million units per annum for that particular purpose they ought to base their tariffs from the outset upon the reduced costs of production which will accrue when the additional half-million units are being supplied. About 18 months ago I altered my house very considerably and installed electrical appliances throughout, including an automatic water heater. The last-mentioned apparatus has a storage capacity of 12 gallons and a maximum output of 62 gallons in 24 hours; it is thermostatically controlled, the electric current being cut off when the temperature of the water reaches 180° F. I used tin-lined pipes and a special dustproof cistern; as a result the water can be, and is, used for drinking and cooking as well as for bathroom and washing purposes. Six persons are living in the house, and occasionally a visitor. The consumption of electrical energy for water heating over the 12 months ended December 1914 averaged 12·8 units per day, which represents a load factor of approximately 50 per cent. That brings me back to the sentence on the first page of the paper: "Although willing to supply energy on, say, a 25 per cent load factor at $\frac{1}{2}$d. per unit, he (the station engineer) sees a difficulty in supplying on a 100 per cent load factor at $\frac{1}{4}$d. per unit." If $\frac{1}{2}$d. a unit is a fair price—and I think it has been proved to be so in many cases—for a 25 per cent load factor, $\frac{1}{3}$d. is certainly a fair price for a 50 per cent load factor. If I had to install the apparatus again I would fix a 25-gallon heater in place of the 12-gallon; and instead of a 1 kw. heating element I should use a $\frac{1}{2}$ kw. one, so that the load factor would be 100 per cent. With that load factor a fixed price of 4d. per day would yield a handsome profit to the supply station, because if the consumer uses the heater continuously at $\frac{1}{2}$ kw. he can consume 12 units a day only as a maximum. It is a great convenience and advantage to be able to draw water at 180° F. at any time night and day, winter and summer, and to use it if necessary for drinking purposes. The author subsequently mentions that he has put in a coke stove which keeps the water on the simmer. Coke-fired heaters furnish much more water than can be used by an ordinary household; they involve extra labour, and if water is kept on the simmer it cannot be used for cooking purposes, because it gets a very nasty taste. The water that comes from the heater I use is always fresh, and if a cup of tea is made with it it is quite as good as if the water was boiled only a minute or two before. It also saves the excessive use of hot-plates on the electric cooker, which we all know are very inefficient. I should like to mention what is called in the north a "set pot." At the time I installed the above apparatus I had a fairly large set-pot made of copper, carefully lined to prevent radiation and cooling losses. With the wooden cover upon it I found that to make up these losses alone required no less than 3 kilowatts, so that I had to give up the idea. Passing on to the question of plugs, in view of the increased rating and size of radiators and other consuming devices I think the sooner the ordinary wall plug is done away with the better, except perhaps for electric irons, because it is a source of danger and always a nuisance; there is a general tendency at the present day to substitute large switches for such plugs. Maintenance, mentioned at the end of the paper, seems to me a very serious matter indeed, because, notwithstanding all the progress that has been made in electric cooking up to the present, I think it is not in such a condition that central-station engineers can recommend it, without qualification, to a consumer. I look upon the electric cooker to-day as in very much the same condition as electric heating was when the long tubular lamps were first used on radiators. The electric "fire" has brought about a change and can now be recommended with absolute confidence. At the present time, however, electric

[illegible]

Mr. C. H. W[illegible] [illegible] range. That is very satisfactory, but I am afraid that [illegible] will retard electric cooking more than claiming for it what it cannot do. I have always been very much surprised at [illegible] go further. I think the author has probably put his finger [illegible] matter whether the cooking is done by electricity, gas, or [illegible] of electricity is that it enables the temperature to be much more readily controlled. One very important point, which I think probably militates more against the growth of electric cooking than anything else, is the question of heating water. I had occasion to go into the question of heating water in connection with the galleys for warships, and I found that if I wanted to do the heating of the water electrically I should require more power than there was in the ship. I am firmly convinced that unless and until electrical engineers will give up the idea of the electrical heating of water for baths, etc., they will make no great progress with electric cooking. It is very much better to recognize the limitations. I firmly believe that for ordinary cooking purposes nothing can beat electrical methods, but I am equally convinced that it is very difficult to beat a coal stove, or preferably a coke stove, for heating water. In an ordinary house, hot water is a great advantage, especially if the hot-water reservoir is fixed in the bathroom, since the heat lost by radiation is exceedingly useful. Consumers do not want to have to be economical in the hot water that is used. The tap must be allowed to run so as to get rid of the cold water in the pipes. What [illegible] mentioned? Practically an unlimited supply is wanted, and that is obtained with a coal or a coke fire. I do not believe that even a 100 per cent load factor would enable us to compete in that direction, and if we persist in trying to do so we shall only stifle the adoption of electrical [illegible] elements. With regard to the c[illegible] [illegible] which I wish to invite the attention of this meeting, [illegible] taking that matter up and has already standardized the [illegible] which I am Chairman has gone into this question, and has [illegible] ings have been held, but there seems to be a great diversity of opinion as to the desirability of any standardization whatever in connection with electric [illegible] The manufacturers are not very eager [illegible] When should we standardize? Should we [illegible] the very beginning before practice has settled down, so as to give the manufacturers leading dimensions to work to? Or should we give people a free hand and wait until every[illegible] standard that will be a mean of the various practices that [illegible] dimensions and requirements could [illegible] be set up at the present time in [illegible] apparatus. For example, if the floor space of the oven were standardized that would settle the size of the baking-dishes and things that have to be used inside the oven. [illegible] that have to go on the hot-plates have a rim round the bottom. I am strongly of the opinion that there are certain things which could well be standardized. There are other points which are doubtful, such as the position of switches, but it would be most helpful to the Engineering Standards Committee if those taking part in this discussion would state their views on this [illegible] they may be they must of necessity have ever[illegible] Now cooking is as old as the hills, and apparatus in connection with it has reached a high state of development and embodies the results of long experience of cooking experts.

Mr. Wood. It must be remembered that cooking is effected by heat and heat alone, and that the only function of electricity in "electrical" cooking is to produce that heat. Is it not reasonable then to utilize the experience of those who have produced the existing coal and gas ranges and graft on to them the newer agent? I am convinced that the development of electrical cooking can best be attained on these lines. Let electrical manufacturers work hand in hand with the cooking-range makers, and not only will their designs be thoroughly practical and acceptable to the cook but they will reach a clientele which they could never get in any other way.

Mr. Allen. Mr. S. T. ALLEN: I cannot conceive that this paper expresses the opinions of electric cooking consumers generally, and there are very few remarks in it which I imagine would come from an ordinary non-technical consumer. I thoroughly agree with the author that we ought to pay more attention to the views of consumers. We must remember that habits have been acquired by past generations in connection with cooking, and should have a certain respect paid to them. In the first paragraph the author states that because a large consumer has a large cooker and therefore uses more current a better load factor prevails. I cannot understand that statement. It is not always the case in my experience. It would be of great interest if the author would state the dimensions of the oven of his cooker, because that is an important point in considering the figures that he gives. My experience of a large number of cookers in ordinary households, averaging about six persons per household, is that the usual consumption is about 1·6 units per person per day. That is a little lower than the figure given by the author, but perhaps the cooker which he uses may have something to do with it. The figures given on page 474 have interested me considerably. Dealing with the first set, I notice that the electrical energy for light and other purposes previous to the adoption of electric cooking cost £9 per annum, whereas in the second set of figures, when electric cooking was adopted, the electrical energy for light and other purposes cost £2 16s. 3d. I should like to know why there was a reduction in the lighting account. The conclusion that I have come to is that the fixed charge for the lighting has been included with the cooking. Also, where does the heating come in in this account. Is it included under "electrical energy for light and other purposes"? With regard to the outlay, I am sorry that the author has included in the paper that total of £45 11s. 3d. I did not know that it was compulsory to use steel tubing for the wiring required with electric cooking apparatus, but the author implies that that is the case. If not, why did he provide expensive steel tubing and so increase the cost? I think wood casing could have been used. I agree with the author's remarks in regard to earthing, but I do not agree with his statement that a householder often does not mind spending a considerable sum on an electric cooker; at any rate I have not met such householders. They always seriously object to paying such sums as the author has mentioned. Again, I think it has now become universal for a pilot lamp and a fuse to be put on each circuit, and it is becoming exceptional for the modern cooker to have only one fuse. I do not at all agree with the author's remarks in connection with the thermometer. I think if we have been able to cook satisfactorily with coal and gas for the last 50 or 100 years without a thermometer we can do without a thermometer on an electric oven. It is an unnecessary complication. The author also says that the error of the thermometer can easily be corrected. Does he mean that the consumer should make this error allowance, or should it be done by the electrical engineer? Another very important point is that in the author's experience the shrinkage of meat depends upon the temperature at which it is cooked. I thought that was the reason always given by electrical engineers why electric cooking is so much more satisfactory than cooking by gas or coal, and why the shrinkage is less. Gas and coal ovens have very bad regulation; the temperature often becomes excessive, and that is why electric cooking is so much better, since we are better able to regulate the temperature. With regard to plugs, the author suggests the adoption of an earthed ring. It seems to me that an earthed ring would make the plug still more dangerous. If somebody in the dark touched the pin of the plug with his finger when putting the plug in sideways he would earth one side through his finger, and the other side of the plug might be over the contact. The interesting tests on flexible wires have little bearing on the question of electric cooking. The author does not appear to have mentioned the flexible cord in which a steel wire is incorporated in the copper. That has proved very successful. Neither is there any reference to the "cab-tyre-sheathed" cable, which should be carefully considered in this connection. With regard to the powers required in order to enforce earthing, I always enforce it, and I always shall; and I think electrical engineers do not require any further authority to do so. One of the most valuable points which the author mentions is the use of unearthed utensils alongside earthed apparatus. That is a point which is often forgotten. With regard to the rateable-value tariff to which the author has referred, although I do not say that it will not be superseded in the future by a better differential system of charging, I feel convinced, from my experience in two towns where I have introduced the system, that it is the one which is best understood by consumers. It is the most popular, and I am convinced that it is the best system that has yet been adopted for introducing electric cooking and heating. On page 482 is the statement, "As a possible consumer the author objects to paying a heavy primary charge when he may be using only a cooker." I do not know of any case where a rateable-value system has ever been made anything but optional. There is always a flat rate available. On the same page he also remarks that "During the last few years many station engineers have complained that the lighting load was much reduced through the use of metal-filament lamps; yet there seems to be no tendency for the percentage charged on the rateable value to be reduced." No engineer who has had a rateable-value system in use has, I think, ever made that complaint. It is obvious that it would be to his advantage if the fixed charges were guaranteed, but engineers in towns where a flat rate is in operation might have complained.

Mr. Downe. Mr. R. S. DOWNE: I cannot help thinking that the author has looked at the subject from the point of view of a technical consumer, because the point of view of

[illegible] at the end of the test weighed 101 l[illegible] in cooking in the [illegible] carrying out catering on such a [illegible] of $1\frac{1}{2}$ units per head, so that between $1\frac{1}{2}$ and 2 units is [illegible] and we estimate that 6,000 of those, in a purely residential [illegible] I also estimate [illegible] the same rate of 2,500 units is used per cooker we shall double our output of 3,000,000 units per annum. Some members may say that if we put 1,200 5-kw. cookers on the mains a large additional load due to that 6,000 kilowatts of apparatus will come on the peak. Our present con- [illegible]

[illegible] lation will have to be carried out on exactly similar lines to those on which gas cookers are let out on hire all [illegible] cookers are, and I believe that in the immediate future the cost of installing electric cookers of similar capacity, including wiring, will not exceed £10. I am in entire agreement with Mr. Wordingham's remarks [illegible] cultivate that load without trying to do the impossible. My experience of electric water heaters has not been [illegible] and went in for the "all electric" idea. We installed two electric water heaters, and they cost us, including the fitting up, £160. On a 3 months' trial they gave very indifferent results, the average number of units being [illegible] 7s. per week. Unless it is possible to charge for electrical energy at a rate which is not likely to be feasible in London for a very long time, electric water heating is out of the question. The difficulties before us are not [illegible] tricity-supply business has been built up. The ga[illegible] advent of electric cooking on an extensive scale will very shortly arrive. The advantages of the non-combustion process as against the combustion process are so con- [illegible] have, and the latter, having probably a very [illegible]

Mr. Grogan. diversity factor, will give a better load factor on the station itself. With regard to the author's remarks on the electric heating of water, I am very glad to see that he has installed a coke boiler, because if he had used an electric boiler the results would have been still worse. The author suggests that electricity should be supplied at $\frac{1}{4}$d. a unit. I propose to leave central-station engineers to deal with that figure. Taking 0·2d. as the cost of coal per unit generated, and deducting it from 0·25d. leaves only 0·05d. per unit for the capital and standing charges, which with 100 per cent load factor would mean £1 16s. 5d. per annum per kilowatt installed. Even at $\frac{1}{4}$d. per unit with only a 500-watt heater the cost would be £4 11s. 0d. per annum, and the amount of hot water provided by this little apparatus is infinitesimal compared with the water supplied from a coke boiler. The coke boiler mentioned will cost on the average about 1s. or 2s. per week, the cost varying with the number of persons in the family. The next point that I wish to make is that if anyone desires to use electrical apparatus in order to produce hot water in bulk it may sometimes be employed, but only where small quantities of hot water are required or where for large quantities we are prepared to pay for the convenience. In such cases a 6 to 10 kw. heater should be used, with a hot storage tank and thermostatic control. That will give every satisfaction. With regard to the question of the consumption of energy for cooking, a very fair estimate is 1,500 to 2,500 units per annum for a family of six. In the author's case for nine in family I should allow a further 1,000 units on the higher figure, or say 3,500 units per annum. I rang up a householder in Hampstead yesterday in order to ascertain the results that he was obtaining with electric cooking, and I found that over a period of 44 weeks the average consumption was 65 units per week against the 110 units in the author's case, the number of persons in the household in question being eight. Either the author's cook has been very extravagant, or the apparatus has been inefficient. In the household at Hampstead to which I have referred a coke boiler has been installed and has been operated at an average of 2s. per week. The author's deduction that electric cooking will cost for a family of nine £8 19s. 0d. more per annum than if coal had been used is quite wrong according to general experience. I regard this paper as an attack upon the excellent progress made in the electric cooking industry during the last few years. As to the outlay, the first item of £23 15s. 6d. for the electric cooker is made up as follows: £16 10s. 0d. for the cooker itself, nickel plating £1 10s. 0d., switchboard £3 10s. 0d., connections £1 15s. 0d., and 10s. 6d. for a useless thermometer. In addition to the £3 10s. 0d. already included for the switchboard, the author has actually spent £9 4s. 5d. for the wiring, which is an absurdly high figure. There are other types of electric cookers which the author might have used and which can be bought for about £17 10s. complete. Again, why has the author inflated the cost of the cooking apparatus by adding the cost of the coke boiler, which is given in the paper as about 10 guineas? This is about 4 guineas above list price, including erection and connections. The author could have probably got it installed at a lower price if he had gone to an ordinary plumber. Again, why does not the author mention that he got a very much better service from this coke boiler than he ever got before from the coal fire? He must have done, because that is the general experience. In connection with the outlay, I want to Mr. Gro emphasize the importance of hiring out electric cookers. The author has almost neglected this aspect in the paper. There are already between 30 and 40 municipalities or companies which are doing that to-day, and it is the only way to succeed with the cooking load.

(*Communicated*): This is all the more necessary as it is in the smaller household where the mistress either cooks for herself, or closely superintends, that the advantages of electric cooking are appreciated. As to the shrinkage in cooking meat, it has been established for years that the saving in favour of electric cooking is due to the ability to cook at a lower temperature. Even the author's figures show a saving of 10 per cent at what he calls "normal temperature" (see Tables 2 and 3), but in the matter following he explains his view of normal temperature, viz. between 250° F. and 300° F. The author would have shown better results in favour of electricity had he studied the elements of ordinary cooking. I would refer him to such well-known writers as Sir Henry Thompson ("Food and Feeding"), and Robert Hutchison ("Food and the Principles of Dietetics"). He will find that after sealing the meat at a temperature of 250° F. or over it is better to cook at 200° F. or even less. The author does not state, as he should do, that the meat cooked by electricity is of better quality, and I would refer him to a paper which I read last year at Wolverhampton.* Another point about Tables 2 and 3; will the author kindly state whether "original weight" for rolled ribs of beef refers to the weight of the meat with or without the bone. This joint has about 20 per cent weight of bone, and if he has taken original weight as rolled without bone then his percentage losses are too high when compared with other published results. This point will not, of course, alter his comparative tests but he should make it clear. I have referred to the thermometer attached to the oven as being useless. Not once, but on many occasions I have found the consumer being led astray by a thermometer fixed to the oven and reading 100° F. too low. The portable oven referred to in the paper as original is not new. It has been supplied with one type of apparatus now for several years and proved to be most useful. Regarding the flexible cable tests, I do not see a test on that most commonly used in connection with cookers, viz. ordinary workshop flexible in flexible metallic tubing. The author makes a good point on insisting on earthing cookers. Responsible manufacturers have not only always advised this but have provided special 3-pin earthing plugs with the apparatus so that the latter cannot be put on circuit without completing the earth circuit. It is admitted that some contractors do not always join up an earth-wire to the terminal provided, but as the majority of electric cooking installations are hired from the supply authority their engineer may be safely left to see that the installation is properly "earthed." Surely he does not want to be directed by a special rule from the Council of the Institution as suggested by the author. As to tariffs, my experience is that a primary charge plus a low running price per unit has been most useful in developing electric cooking loads, but the running cost should not be so low that a high charge becomes necessary for the hiring rate of the apparatus. To meet competition it is essential to establish a low

* *Electrician*, vol. 72, p. 864, 1914.

[illegible]

obtainable. That being so, I think it is time that the manufacturers investigated the difficulties that beset a number of supply engineers in having to reduce their tariff [illegible] of maintenance must be seriously considered in conjunction with electric cooking.

Mr. H. T. Harrison: The title of this paper undoubtedly [illegible] being turned toward the consumer, but on reading the [illegible] do with it. I have been a consumer of electricity for [illegible] somewhat different from the author's. In the first place, the prime cost of the installation was very much lower. The annual costs could hardly be compared, since the electric supply company charges me 1½d. per unit for [illegible] years ago, but I find there is not a difference of 12s. per annum in the total cost of gas, coal, and electricity during any one of those five years, and it is impossible to tell from the accounts when I started to use electric cooking. That shows that even at 1½d. per unit electric cooking is not expensive. By the word "cooking" I do not include "cooking" water. I have never attempted to heat water

[illegible] total cost.

[illegible] be [illegible] oven itself. When such [illegible] should not enter the oven, the efficiency is very much [illegible] heating elements directly in the oven, which should result [illegible] oven which I have used in my [illegible] given such extremely efficient results, and I think [illegible] people would be surprised to see the figures which can be obtained with an oven of correct design as regards [illegible] and one which is properly protected from heat losses, not [illegible] devices, and which are designed with [illegible] have found, as no doubt others have found, that unless it is made simple to keep an oven in efficient [illegible] tion, the average cook or domestic servant [illegible] all the advantages [illegible]

Mr. W. M. Mordey: The [illegible] electricity when the oven is too hot, 23½ per cent; and with electricity, when the temperature is "normal," 14½ per cent. Mr. Downe has just given, as an instance, a loss [illegible]

M. Mercier. Table 3, for electric cooking, it is seen that the proportion of loss is practically the same whether the joint is fat or not; that being so, I am driven to ask whether the actual loss is anything but water, and if it is water, whether it is right to value it at 6d. or 1s. per lb., as is done in the two cases quoted. My own view is that that is rather a high rate for hot water. I do not mean to say that no harm is done by evaporating meat to dryness—that is another point—that is bad cooking and there is a remedy for it more or less complete, viz. to make the oven steam-tight and so get an atmosphere of saturated steam at the cooking temperature, when the evaporation of water from the joint will cease. That is true for a gas oven, coal oven, or an electric oven. One other point; electric cooking has, or should have, a great advantage as regards the consumption of energy in cooking things that take a long time, because almost all the energy necessary is that required to bring the food up to the cooking temperature. To keep it at that temperature should in practice hardly need any more energy. With electric cooking the source of heat is, or should be, enclosed in the same heat-insulated space as the thing to be cooked. The escape of heat is therefore controllable. It mainly depends on the lagging. In comparing, or standardizing electric cooking apparatus, it should be easy to give proper value to this point, as the measurement of the energy necessary to maintain some given internal temperature presents no difficulties. The determination of the true point of economy in such an apparatus would be very interesting—I mean the point at which it begins to be profitable to spend money on energy rather than on lagging. It would not be surprising to find, for example, that it would be true economy to lag an electric oven and its heating element on the Thermos-flask principle.

Mr. Pinkney. Mr. W. F. T. PINKNEY: With regard to the question of the amount of energy consumed by an electric cooker, I consider myself in the position of an ordinary consumer in having an alien cook whose limited knowledge of English made control a difficulty. I decided that for the first year's running of the electric cooker I would leave her to her own devices and see what the result was. The consumption of energy is now about 1·3 units per head per day, which is the average over six months for a household of three, that is to say a very small one. The author points out that if the number of persons in the household is increased the consumption should be reduced accordingly per head. I am quite convinced that the figure of 1·3 units per head can be reduced to 1 unit, and possibly less. According to our method of computation the probable current consumption for a household of eight or nine persons was 3,600 units per annum, which is practically the same as the figures given by Mr. Grogan. I do not know what the author's tariff was, but assuming the standing charges were £6 5s. od., the 3,600 units at $\frac{3}{4}$d. per unit would cost £17 10s. od., which together with the lighting, heating, and coal, would amount to approximately £26 19s. od. That shows a very big saving on the figures that he has given us. I cannot see why with a careful cook he uses 2 units per day. I think there is no doubt that branch fuses should be adopted in cookers, and also that a cook would never use the thermometer. I should like to draw attention to the consumption curves, notably that for Saturday, which seldom touches zero and indicates a very long-hour use of the cooker.

Mr. Pinkney. (*Communicated*): With regard to earthing, the author states that there is no authority having the power to enforce such earthing of cookers, but surely the supply authority in every district is able to enforce this and should certainly do so. In drawing attention to unearthed accessory apparatus placed near an earthed cooker, the author touches on one of the most important points in connection with cooking, as this represents a real danger, more especially as it is a very common practice to have a self-contained kettle used in conjunction with a cooker. There are two possible ways of getting over the difficulty; one is to arrange for all accessory apparatus to be earthed through an armoured flexible; another is to see that no plug is fixed anywhere near the cooker, so that it is impossible for the accessory apparatus to be connected up within reach of the cooker. The author suggests that an assessment based on a rateable-value tariff should be treated as an elastic quantity, subject to the discretion of the Engineer, but this would not prove feasible in practice. I have also not found that a higher assessment generally means a proportionately higher load factor.

Professor Morris. Professor J. T. MORRIS: I am strongly of the opinion that a consumer should be able to hire an electric cooker if he desires to do so, because he may change from one district to another in which the pressure is quite different and where the first cooker would be useless. It is important that, as far as possible, the cost of maintenance of electric cookers should be reduced to as low a figure as possible. I am not in accord with the author in regard to the future of heating water by electricity. I agree with Mr. Wordingham and other speakers that it is much better left alone, at any rate for some time to come, and that only the actual cooking should be carried out electrically because the advantages in that case are very great. With regard to heating water by a coke boiler, to which several previous speakers have referred, I find from personal experience, ranging over three years, that $3\frac{1}{2}$d. a day for a household of five or six is a cost which is steadily maintained, and that for that cost an ample supply of hot water can be had throughout the house day and night for all purposes. That figure cannot be approached by electrical methods. I find that the amount of electricity used per person per day in this household of five or six is $1\frac{3}{4}$ units. With regard to the position of the switches, I entirely agree with the author that they should be put in a place in which they can be easily seen and got at, but I think he is inconsistent when he says that the thermometer should be put on the oven, the natural position of which is low down. If the thermometer could be raised up so that it was alongside the switches and had a large scale, I think it might be used. Personally I think the cook has been rather too much maligned. We must study the habits of the cook if we are to make a success of electric cooking. My cook has operated the electrical cooking apparatus for three years and tells me that she has never received an electrical shock. That should always be the case: the apparatus must be installed so that there is no question of anyone getting a shock. I think the author makes a good point with regard to portable ovens. The question of heating up dishes is one which occurs in all households, and some form of cover over a little plate would be a very useful adjunct. I agree that the earthing wire of the oven often looks a very temporary arrange-

[illegible] more permanent [illegible]

Mr. A. H. [illegible] dry places was compulsory. I should not think of instal- [illegible] Selfridge & Co. have placed an order with us for what will probably be the largest electric staff kitchen in the world. It will eventually deal with the cooking for the whole of their employees, and we may safely assume, I think, that [illegible]

Mr. W. [illegible] Messrs. Purcell and Nobbs, and is fitted with top and [illegible]

[illegible] conditions, and have these two points [illegible] of other consumers in London. In the [illegible] person per day over the whole year. [illegible] all current consumed for bread [illegible] used on this cooker. [illegible] newer condition the cost of electrical energy for [illegible] electricity only. Under the old method his coal cost him [illegible] as given by the author, "is the increase [illegible] cost, but [illegible] been overcharged. [illegible]

Mr. Gill

one house, one for a water heater and one for an electric cooker. The route length of each circuit was 30 yards, and one was wired with 7/15 S.W.G. and one with 7/20 S.W.G., complete with cast-iron switches and fuses, the wires being run in screwed tubing. The cost for the whole job was £10. This price is in comparison with all prices which we quote in the Newcastle district. The author refers to armoured cable for wiring for cookers. I quite agree that cooking wiring can be done under this arrangement. Personally I favour "cab-tyre-sheathed" cable for this class of work, and this cable can be easily removed at a later date if necessary. On page 475 under "Details of cookers," I quite agree with the author that it is essential that a double-pole switch should be fixed quite close to the cooker. I firmly believe in separate switchboards fixed on the wall, slightly to the right or left of the cooker, according as the position requires, also that each hot-plate or section of the cooker should have a separate switch and fuse in addition to the main fuses. In the majority of cases one pilot lamp is usually sufficient, but where large cookers are installed, and the cooking is likely to be of considerable extent, I always prefer separate pilot lamps so as to prevent waste. I quite agree with the author that it is extremely bad practice to mount switches on the side of the cooker itself. As he says, they are very difficult to read, and are really a nuisance, especially when children are about, as they are apt to consider that these switches are fixed for them to play with. The author has undoubtedly put forward a very good argument in favour of using thermometers on oven doors. I have not yet, however, found the necessity of these. I find that the usual call by the lady cook or demonstrator is sufficient to find out if there is any misunderstanding in regard to the operation of the oven, and a short talk usually puts these matters right. We have not had any difficulty whatever in securing our customer's satisfaction on this point. The greatest difficulty we find with cookers is the question of hot-plates, mainly on account of their slow heating compared with coal or gas. No doubt the author has also experienced this. With regard to earthing, I cannot understand any engineer fixing an electric cooker without ascertaining that it is efficiently earthed. We make it a practice that all cooking apparatus of the larger type is earthed by a special earth-wire. Where portable apparatus has to be used in proximity with the larger apparatus, such as cookers or the large type of breakfast cookers, we endeavour to fix a 3-core flexible wire with an earth connector. Upon the question of maintenance, it is very seldom that one meets a consumer who purchases his own cooker. In fully 99 per cent of the cases the cooker is hired from the electricity supply company, who carry out their own repairs. These repairs have been included in the rental for the hire. I do not propose to discuss the question of meat shrinkage, but perhaps an experience of mine may be of interest. During last year I removed from one house to another where the voltage was different, and at the time of removal I was unable to obtain a cooker suitable for the new pressure. I was, consequently, without an electric cooker for two months. Unfortunately, at the same time one of the servants left, and there was thus one person less in the household. During this period all cooking was carried out on the coal fire. We purchased our meat from the same butcher, and the bill increased by 15s. for two months. After the electric cooker was installed, we returned to our former accounts with the butcher. This I consider proves conclusively that there is something in the question of saving on the meat shrinkage. On page 476 the author refers to the necessity of the apparatus heating up quickly. I quite agree with him on this question. It is certain that if an oven heats up quickly it is sure to give the consumer satisfaction. An electric cooker, unlike a coal oven, is only heated when it is required, and no time should be wasted during the stage of the initial heating up. Unfortunately, in the case of hot-plates a good deal of time is lost before the hot-plate attains a useful working temperature.

Mr. Moore

Mr. A. N. MOORE: It is very encouraging to find a paper of this nature being read before the Institution. It must be particularly encouraging to those of the members who have taken such an active interest in the advocacy of cheap units for domestic purposes. Thanks for this are particularly due to one or two of the more responsible and prominent members who have expressed such decided opinions on the value of the domestic load and have bestowed their benediction on the present heating and cooking campaign. My only regret is that the author should rather have missed the opportunity of presenting the subject to us in what might have been a much more useful form. It is unfortunate that he should, in his attempt to deal with the general question of cooking from the consumer's point of view, have selected what is obviously an exceptional case upon which to base his deductions on the general case. I am glad to see that he has dealt with the question of the saving due to shrinkage. A more futile suggestion or absurd position to take up from the point of view of propaganda than this it is hard to conceive; and I cannot understand any responsible manufacturing firm approving of it being put forward to the consumer, as an inducement to purchase, that he will save so much on his bill by the reduced shrinkage of meat. On this question the author has not put forward a point which I think he might have done. Taking his own figures of an average weekly consumption of 100 units at approximately 1d. per unit, this represents a weekly bill for energy of 8s. 4d. If, as the author states, the consumer saves, due to reduction in shrinkage, 10 per cent over coal or gas, this by no means represents the actual saving per week and is quite misleading. Rightly the author points out that joints are not being cooked every day, and a fair assumption would be two joints a week, which on the average would require 7 units; that is to say, a 10 per cent saving is only effected on 7 per cent of the total weekly bill. In other words the net cash saving would be 0·34d. only. I am surprised to hear the author suggesting that central-station engineers are more concerned in competing with coal fires than with gas. No engineer I think will agree with him on this point. In fact I am rather surprised that the author has evidently considered it almost unnecessary to touch on the gas question, as hardly any reference is made to it in the paper. The subject of earthing is very important. I know of an instance where the cook who was using an electric cooker had a boiling-ring standing on the cooker, the cooker being efficiently earthed whilst the boiling-ring was unearthed. The result of a fault developing on the flexible wire of the boiling-ring was to cause a severe

[illegible] that a great deal of the present opposition to electric cook- [illegible]

Mr. F. C. Raphael: The author has adopted the con- [illegible] does. Much too great publicity has been given to this extravagant and unsuccessful experiment, and if the [illegible] central-station engineers who are in touch with the users of electric cookers he would have found that his [illegible] have already shown that they must be received with [illegible] would be likely to give trouble; in fact only this afternoon I had my attention called to a short-circuit or earth through a plug which had a ring unfortunately connected to earth and like the collar of that shown in Fig. 2 only sunk. In fumbling to get the plug in, contact was frequently made between one of the pins and the ring by the user. I think most people will agree with me that the chief virtue of the hand-shield plug is not to prevent people getting shocks when putting it in, but to prevent any strain on the flexible wire. The author need not have gone to so much trouble to test flexible wires, because many of us could have told him that if he uses the ordinary circular braided flexible wire it will not kink and will con- [illegible] could also have told him that if he uses tinned vulcanized flexible wire in small sizes the conductors are liable to break owing to the action of the tinning on the thin wire. There is one question which I had hoped would be fully discussed, although it is not mentioned in the paper; it arises in connection with the section of the paper on [illegible] number of kilowatts may, on some distributors, be [illegible] of dividing it into two parts, one connected to each side of [illegible]

[illegible] to adopt the rateable-value system. My bill last year for [illegible] author must undoubtedly know that the attempts in the [illegible] by costly instruments and complicated tariffs have done much to retard progress. Now the Norwich system presents an easily understandable method based on commercial lines, and because it does not mathematically fit every case it is subjected to severe con[illegible] We have the telephone with its fixed charge to include a fixed number of calls, and additional calls on a certain [illegible] of calls allowable but received no rebate. Then the rail- [illegible] from 3 to 12 years half-price, and above 12 [illegible] one charge irrespective of size, weight, or [illegible] the man with an income of £160 per annum or less goes free and the greater the income the greater the rate of tax. Letters are paid at 1d. whether ½ or 4 oz. are sent through [illegible] these reasons the Norwich system will survive all criticism. [illegible] different localities and circumstances, such as g[illegible] the percentage according to the rateable value, or adopting a lower percentage for heating and cooking only, as a fixed charge in respect to the service costs and demand on the station, or allowing so many units free per pound of rateable value, but the principle will remain, viz. a fixed charge reckoned as a percentage of the rateable value plus a small secondary charge for all current consumed. [illegible] there are certain notable omissions. He does not [illegible] state the rateable value of the house. As, however, he quotes in his second table an average [illegible] unit I shall take the same figure for his lighting giving [illegible]

Mr. Pa... cent represents £111 10s. 8d. rateable value, or an annual rent of, say, £138. Thus :—

	£	s	d
Electrical energy for light	2	10	3
" " cooking	21	10	0
Meters	1	0	0
	25	15	3
Less 5,674 units at ½d.	11	16	5
	13	18	10

£13 18s. 10d. = 12½ per cent of 111 10 8

If, however, the percentage is only 10 per cent as in some cases, then the rateable value would be £139, or a rent of say £160 per annum. I cannot conceive a house of such a size using only 5,674 units per annum. If it is in fact rated at less than the figure deduced above, then the Norwich system will show a saving; if on the other hand it is of a higher rateable value, then it is one of the exceptions but for which the Norwich system would be perfect. In support of my contention that the consumption is small for such a house I give the following actual examples.

Rateable Value	Units per Annum
£31	4,073
£38	5,267
£38	6,683
£43	6,502
£94	6,656
£130	10,270 (7 months)

No doubt the fifth example given will be taken by the author in support of his contention, but knowing the full circumstances I say that the difference is more than justified; both consumers are receiving equitable treatment and both are quite satisfied. Of course the examples given are where electrical heating and cooking are employed. I could give many other examples of consumers using lighting only who, by adopting the rateable-value system, pay approximately the same as on the flat rate; which means that when they feel inclined to adopt electric heating and cooking it will not cost them more than ½d. per unit. The author's concluding remarks dispel any fear as to the effect on the system of such an additional load. Finally, as to his contention in regard to the business which we do not succeed in attracting: I say that we have secured a great deal of business—lighting, heating, and cooking—by the Norwich or rateable-value tariff, and no other tariff would have secured this business. Further, I am certain that the business that we have not so far secured would not be accelerated in the slightest by any addition to or variation of the present rateable-value tariff or by the adoption of some other tariff.

Mr. Cooper. Mr. W. R. COOPER (*in reply*): The discussion has been marked by some of the most illogical statements I have ever heard. It has also been marked by extreme sensitiveness to criticism on the part of certain members. This, it seems to me, is unfortunate, and I can only conclude that these sensitive members have an inordinate fear of the gas technical Press. The domestic consumer, with whom I deal in the paper, is not going to trouble about what is written in the gas Press, but will be guided by whether electric cooking is a good thing and whether his interests are properly considered. I make it clear in the paper that I am dealing with a particular class of consumer, the one who is now depending on coal and who requires a fair amount of cooking, and I do not generalize, notwithstanding statements to the contrary. Briefly, I say that electric cooking is very good and that with a suitable tariff, such as is given by certain "Point Five" engineers, the cost of electric cooking (including all charges for hot water with a separate coke boiler) is about the same as with coal. Personally I regard this as a very satisfactory result, but some speakers (without foundation, in my opinion) seem to regard it as a most damaging statement. I do not see any reason to alter my view. Some speakers (*e.g.* Mr. Grogan) seem to think I contend that cooking by electricity must be more expensive than with coal. I say nothing of the kind. The tariff cannot be neglected in such a question.

I think it best to deal first with some general points, and then with some of the speakers' remarks in detail. Many of the criticisms have been answered by one speaker or another. As an instance of illogical statements, let me take the question of the consumption of energy per person per day. I give a figure of 1·6–2·0 units. In criticizing these figures several speakers (notably Mr. Grogan) insist on comparing incomparables. They mention that some consumer with an indefinite cooker and an indefinite menu obtained lower figures than mine, and *therefore* my figures must be wrong. If an engineer were to say that because a certain tramway consumes energy at the rate of one unit per car-mile therefore a railway should also run with a consumption of one unit per car-mile, I am quite sure that he would be regarded by Mr. Grogan and others as a technical lunatic. Yet Mr. Grogan argues on those lines in regard to electric cooking. Fig. A herewith is

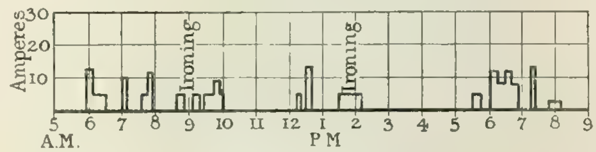


FIG. A.—Record of Electric Cooking, by J. R. CRAVATH, Friday, 4 January, 1907.

reproduced from a paper which I read before the Institution in 1908,* and shows a record of a certain household. A casual comparison of this with the records given in the present paper ought to be enough to show that these two cases could not be justly compared, and so it is with many others. Mr. Seabrook rightly remarks that it is no good comparing what one household does with what another does. In the case which I consider there were generally three hot meals per day, and for the menu that is followed I do not consider the consumption is high—a view which is supported by Mr. Downe's figure of 1¾ units. I quite admit that lower consumptions are obtainable under other conditions and a different menu. They are matters of common knowledge. All this, it seems to me, should be common sense and should not give rise to acrimonious discussion.

There has been some criticism of the title of the paper on the ground that I am a technical and not a lay con-

* W. R. COOPER. Domestic electricity supply (including heating and cooking) as affected by tariffs. *Journal I.E.E.*, vol. 42, p. 26, 1909.

[illegible] readily enough. It therefore seems curious that some members (while very sensitive to the mildest criticism) should proceed to condemn electric water heating unreservedly if they do not themselves happen to have anything to offer in this direction. I think this narrowness of view is unfortunate. In any case it is more logical to condemn a thing after use than before.

My attitude towards the electric heating of water is that though it is not wise to adopt it where the quantity of water is very large, the method has very marked advantages. Mr. Downe might easily have satisfied himself that in his case electricity would have been more expensive than coke, without going to the expense of actually trying it. Personally I would not have tried it in that case, nor yet in a warship. Even so, ½d. per unit for thermal storage is not a fair charge. At ⅓d. per unit the cost would have been 10s. as compared with 7s. for coke, which is not such a very great difference. Of course, a heater of, say, 10 kw. capacity for water can be used, as Mr. Grogan suggests, but then it will be in circuit only intermittently and therefore the energy cannot be obtained on such advantageous terms. Thus the essential part—a suitable tariff—is absent.

What is forgotten by many speakers, and what is well set forth by Mr. Wilkinson, is the very great convenience of electrically-heated water, and for this it may be well worth paying something. Even with a coke boiler the water is not necessarily always hot, particularly in the early morning, and servants have a remarkable facility for letting the fire out when the water ought to be hot. With electric water heating this all becomes automatic.

As regards station costs, Mr. Grogan must remember that it costs very little to produce additional energy on a 100 per cent load factor. In any case I am content to

[illegible] have not tried.

[illegible] aided by the thermometer.

Mr. Grogan implies that the temperature shown by the thermometer is the temperature at which the meat was cooked, yet he complains that these thermometers are, as a rule, wholly inaccurate. In regard to the first point, I suggest nothing of the kind. Obviously the two tempera- [illegible] certain of her cooking. I suggest that she can in the same way get to know her electric oven, and if there is a thermometer she will know it far better than by any other means.

Mr. Grogan thinks that I ought to have cooked at lower temperatures. I found that if I used lower temperatures [illegible] ture, but if Mr. Grogan wishes for that he must issue special rules for the cook and not depend on the usual practice, which I followed. Mr. Grogan's remarks, however, are evidently based on the assumption that the thermometer necessarily indicates the temperature of the meat. In the present instance the thermometer was near the top of the oven and therefore I should expect it to indicate a higher temperature than that of the meat.

Mr. Seabrook remarks that, in his district, if thermometers were fixed they would be removed. If by this he means that the Electricity Department would remove them (and I do not know who else would do so) then I [illegible]

[illegible] shrinkage. Although the shrinkage is greater than I obtained the difference between electric and coal cooking [illegible] sion that I consider the saving in shrinkage to be [illegible] value. This is quite a mistake. In any case it is of [illegible] but more particularly in restaurants (with which type of

Mr. Cooper.

work the paper is not concerned). My only objection is against the domestic consumer being given exaggerated views, such, for example, that he will be able to pay the whole of his electricity bill for cooking by the reduction in his butcher's bill.

As to the load factor of the larger consumer being better than that of the smaller consumer, it seems to me that this follows as a matter of course, because the consumption increases as the number of persons is increased and the number of units per person per day is also greater. This, however, would not be true of a large and a small consumer in the same class, because there is a certain economy as the number of persons in a family increases. What I had in mind was practically the comparison between a consumer who changes from gas and one who changes from coal. I think this is clear from the context.

Some criticisms have been made as to the earthed ring which I propose for plugs. I think it is obvious that if the ring is as deep as the pins are long the difficulties suggested by various speakers do not arise. Of course, if it were a narrow ring there might be trouble, but then the whole object of it would be lost. I do not feel strongly in regard to earthing the ring, and in any case earthing would only be adopted in the kitchen.

As to the earthing of cookers and accessory apparatus, I am glad to find that I am supported by Mr. Nichols Moore, Mr. Allen, and other speakers. Although some seem to think that everything is done that should be done, I believe I am right in saying that there is no compulsion at present about earthing such apparatus in private houses, nor is there any Institution Rule in regard to it. No doubt some engineers see that earthing is properly carried out, but it is common knowledge that this is by no means always the case. I do not wish to dot all the *i*'s and cross all the *t*'s; this should not be necessary.

Some speakers seem to think that I have stated that consumers do not object to purchasing a cooker. That is not quite so. Unfortunately, in many districts consumers cannot hire apparatus; they must purchase or have nothing. What my statement was meant to convey was, that if a consumer is induced to go so far as to purchase a cooker he will probably object to paying a further sum for what seems to him to be useless extras.

Many speakers have emphasized the fact that there is cheaper apparatus to be had. I mention this myself, and therefore I do not understand why this statement was not sufficient. For the particular conditions before me I took the apparatus that I did; under different circumstances I might have taken very much cheaper apparatus. It is purely a question of conditions.

Let me now pass more to the remarks of individual speakers.

Mr. Wilkinson has misunderstood me a little, or perhaps I have not been quite definite enough, in regard to the use of the coke-fired boiler as an auxiliary for cooking. As a rule the heat is scarcely sufficient for boiling, but it is often an advantage to be able to keep a utensil hot (for example, in making porridge) without using a hot-plate for the purpose. When boiling water was required for any purpose the kettle was filled from the hot-water supply and then heated electrically to the boiling point.

I do not agree with Mr. Wordingham that the quick heating of an electric oven militates against cheapness owing to the greater demand on the supply station. This would be true if cooking apparatus were supplied on a maximum-demand tariff, but it never is, for obvious reasons. The station engineer relies on the diversity of the individual demands to render such peaks innocuous. With regard to standardization, to which Mr. Wordingham refers, this is a difficult question. My own feeling is that very little should be done in this direction until electric cookers have somewhat standardized themselves. Otherwise, progress may be hampered through development along some suitable line being prevented. I quite agree that full advantage should be taken of the long experience gained by manufacturers of gas and coal ranges.

In reply to Mr. Allen the dimensions of my oven are $23\frac{1}{2}$ in. high × 16 in. wide × 14 in. deep, excluding the projecting lagging of the oven door. The reduction in the cost of energy for lighting and other uses is due to the fact that the earlier cost is on the maximum-demand system and the later cost is on a tariff with a fixed charge per annum plus a charge per unit. There is no heating, the "other uses" being experimental work. In order to make matters truly comparable, the same number of units were taken in both cases for lighting and "other uses." As to steel tubing, I do not say this is compulsory, but that it is the fashion. Many contractors recognize steel tubing as the standard thing, the line of least resistance, and use it without further consideration. With regard to the tests on flexible wires, three tests (Nos. 11, 12, and 13) are given on flexible wires reinforced with steel wire. I agree with Mr. Allen that the assessment tariff is (as far as I know) always optional, there being as an alternative a flat rate, but the difficulty to the consumer is that the flat rate will probably cost him more and that if the cook is wasteful the payment on account of waste will be more serious.

I fear that Mr. Downe must not expect all would-be cooking consumers to live in his district. It would be a great advantage if all other engineers would follow the enlightened policy of Mr. Downe. There seems to be rather a tendency to regard a "cooker" as being of the same value whatever the rating. Mr. Downe does not give the details of his cooker for £14; as far as I can gather it is smaller than the one to which I refer and of a different type. Also he does not say how he provides for hot water. Further, I state specifically that my prices are "list prices."

Mr. Grogan complains that the cost of connecting up is absurdly high, and at the same time some speakers have objected that I am a technical consumer. Being rather pressed at the time, I lapsed into a lay consumer and allowed the electricity undertaking to connect up.

As to the coke boiler, I do not see why Mr. Grogan would exclude this from the cost of the equipment. The case under consideration is the replacement of a coal range by an electric cooker. The coal range might be used for hot water alone, but it would be very wasteful. The consumer must consider the expenditure as a whole. As to the price of the coke boiler, I do not know whether Mr. Grogan really means that the list price of six guineas includes connecting up. It certainly does not, nor could it include a figure which is necessarily indefinite. Pipe-work is always expensive, and even the ordinary plumber or builder (to whom I *did* go) expects and

[illegible]

[illegible] insulation for wires in cookers. It seems to me that asbestos (though not an ideal material) should be used, [illegible] most usual for this kind of work.

With regard to Mr. Grogan's concluding remark, I did not omit to take advice as he suggests. On the other hand I have not always found such advice to be of the best; in fact, I have even known the advisers to be satisfied with [illegible] proved nothing. In my view it has shown that, for a household of the character described, the cost of cooking electrically on certain tariffs need be no greater than the cost of cooking by coal, and that the consumption per [illegible]

Mr. Harrison does not state the size of his cooker, nor how he heats the water that is used. I do not understand how Mr. Harrison, as an engineer, can sum up the paper in a bald statement to the effect that a certain expenditure gave a minus economy. It should be obvious that the economy, plus or minus, must depend on the tariff, other things being equal. I agree that the electric oven is more efficient than other forms, but what we are ultimately concerned with is cost.

In reply to Mr. Mordey, it is not always easy on inspection to judge the extent to which a joint is "fat" or "lean." I think part of the loss is due to fat going into the pan and part to loss of moisture. The latter cannot, however, be dismissed on that account. I think it may be taken for granted that if more than a certain proportion of moisture is removed the meat suffers as a food. I fear that any attempt to make an oven either moisture-proof or heat-proof would be too expensive, and would in any case be open to the objection that the door must be opened from time to time for operation.

Mr. Pinkney draws attention to the fact that some of the curves show a very long-hour use of the cooker. I have no note of what was cooked on the days when the records were taken, but it must not be forgotten that some dishes take a long time. For example, a steamed pudding takes three hours and some puddings take six hours. In regard to earthing, I believe I am correct in saying that a supply [illegible]

[illegible]

In reply to Mr. Gillott, the [illegible] on the top and bottom, but at the [illegible] consumer would agree with Mr. Gillott's way of looking at [illegible] what the consumer looks at. It is difficult to allocate the fixed charge. The number of units and the average [illegible]

[illegible] the saving in shrinkage. The 10 per cent saving is in the [illegible] therefore worth having. Also, I did not suggest that engineers are more concerned in competing with coal; we are certainly more concerned with competing against gas, but it is also well to see how we stand [illegible]

Mr. Raphael seems to think that the [illegible] why makers have taken the trouble to get out special [illegible]

Mr. Purse has made certain calculations and has drawn certain deductions from them. These, however, are wrong [illegible] charge was higher than ½d., but I have not given full details because the tariff was somewhat tentative. One [illegible] tariffs is that the consumer with a high assessment [illegible] be under certain conditions.

Addendum.—I cannot close this reply without alluding to the very marked difference in tone between the discussion of this paper in London and the discussions at the Local Sections. In the London discussion my views have [illegible] taken in the spirit in which it was written. [illegible] remarks in London showed a desire on the part of speakers to stifle discussion of this important subject. I feel, however, that we must above all [illegible] culties lie, with a view to [illegible]

THE VARIABLE RESISTANCE TO MOTION OFFERED BY THE REGISTERING TRAINS OF ELECTRIC SUPPLY METERS.*

By S. Evershed, Member.

(*Paper received 12 February, 1915.*)

[*Prefatory Note.* The frictional and other resistances to motion inherent in meter trains belong to the troublesome region of things which are too small to be measured by one or two easy experiments and dismissed in half-a-dozen paragraphs, and yet not quite small enough to be ignored altogether. In such a region nothing short of precise measurement and careful analysis can lead to sound conclusions; hence the portentous length of this Report. *Parturiunt montes, nascitur ridiculus mus.* Yet however ridiculous the friction mouse may look, his mischievous propensities are a perennial source of trouble in every kind of motor meter, and it is worth our while to circumvent him, although he cannot be altogether laid by the heels.]

Synopsis of Report.

Introductory.

During the preparation of the amended specification of the Engineering Standards Committee for electric supply meters of the motor type, the Panel appointed by the Sub-committee on Electrical Plant Accessories to assist the chairman in drafting the clauses had under consideration the difficulties that arise in testing meters for accuracy owing to the variable resistance to motion offered by the registering train. At any considerable load these variations in retarding moment do not appreciably affect the speed of the rotor, but the Panel was informed that in many cases the variable resistance of a meter train was sufficient to cause marked changes in speed at loads from one-tenth of full load, downwards; and that although these variations cancel out in actual service they make it difficult to obtain trustworthy figures for accuracy at low loads without spending an inordinate amount of time upon the tests.

The Panel thought it desirable to obtain more precise knowledge of the behaviour of the various kinds of meter train before settling the clauses relating to them, and the British Electrical and Allied Manufacturers' Association was accordingly asked to obtain samples of those in common use, and at the chairman's request the writer undertook an experimental investigation of the causes which lead to a meter train offering a variable resistance to motion and the extent to which the variations affect the speed of the rotor.

General Principles.

The subject is one of considerable complexity, and before dealing with the results obtained by experiment it will be well to begin with a general description of the different types of registering device which are commonly used in electric meters, and incidentally to define some of the terms which will be used in this Report.

A complete meter train comprises a set of registering axles each carrying some means of indication, and a reducing gear through which the registering axles are driven by the rotor. The register axles are invariably geared to each other in the ratio of 10 to 1, the gear being either continuous, in which case the consumption is indicated as a continuously growing quantity; or discontinuous —each axle coming into gear with the next once in each revolution—in which case the consumption is counted unit by unit and registered as a numeral.

Each axle of a continuously geared register indicates by a pointer on a figured dial. This is of course the simplest of all forms of registering devices, and as it is in almost universal use in gas meters it is often described as a "gas meter dial"; in this Report, however, it will be referred to as a *pointer dial* or pointer register. The difficulty of reading a pointer dial is well known to everyone who has to do with meters, and when the register axles are geared together with considerable back-lash, as they should be if the train is to run freely, the pointers sometimes give positively misleading indications.

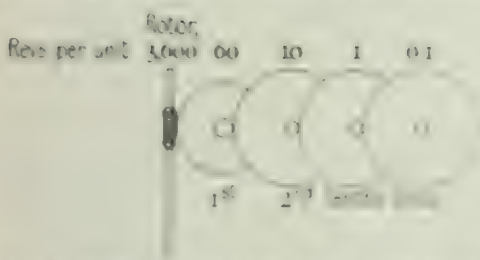
Each axle of a discontinuously geared register carries a disc or cylinder on which the digits from 0 to 9 are marked; these digit wheels (as they may be called) each showing one digit at a time through openings in a dial. Discontinuous gears have been in use for the best part of a century for the purpose of counting the revolutions or strokes of marines engines, pumping engines, and other machinery, and as they are universally and appropriately known as "counters" a meter train which

* Report to the Engineering Standards Sub-committee on Electrical Plant Accessories.

[illegible]

[illegible]

[illegible]



[illegible] Full Load, Worm Drive.

[illegible] taneously. In this Report counters will be distinguished [illegible] they are fitted with a jumper device or not.

[illegible]

The reducing gear which transmits motion from the [illegible] introduce a right-angle drive somewhere in the reducing gear. [illegible] more often than not the worm is on the rotor spindle and the worm wheel on the first axle of the reducing gear.

The various axles of a meter train will be referred to s[illegible]

[illegible]

[illegible]

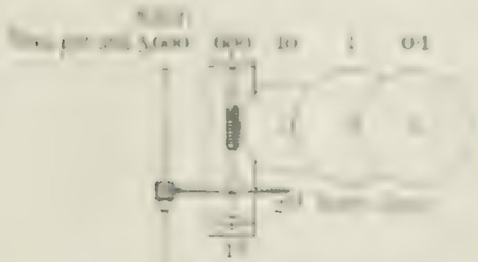
2 7 5 · 6 8

[illegible]

$\frac{1}{1000}$ $\frac{1}{100}$ $\frac{1}{10}$ 1 10

The tenths and [illegible]

[illegible] intended for a 1 kilowatt meter in which [illegible] 60 r.p.m. at full load. The same set of wheels is used for both the worm drive and the spur drive, the first and [illegible]



[illegible]

[illegible] make 60 S/W revs. per kilowatt-hour, and since the tenths axle makes one revolution per Unit the [illegible]

TABLE 1.

[illegible]

[illegible]		[illegible]
tenths	,,	60 S/W ,,
[illegible]		[illegible]
tens		[illegible]

To avoid the continual repetition of long words, the moment of frictional resistance of a spindle or wheel will [illegible] the torque required to overcome it. [illegible]

[illegible]

torque of a meter is given in gramme-centimetres, the gramme will be supposed to have a weight of 1,000 dynes, instead of its legal weight of 981 dynes.*

It may be useful to note that a dyne is the force with which the earth is attracted towards a mass of 1·02 milligrammes held in the hand.

Gear Efficiency.

The efficiency of gearing which will be frequently referred to in this Report is not the overall efficiency obtained by taking all losses into account, but the differential efficiency, namely :—

$$\frac{\text{Increment of resisting moment on driven axle}}{\text{Corresponding increment of torque on driving axle}}.$$

In reckoning this efficiency the only losses taken into account are those caused by the engagement of the gear teeth—tooth losses—and such losses in the bearings as are directly caused by the power which is transmitted. In the case of gearing which, like that in a meter train, runs without lubrication these losses are simply proportional to the speed, and since they are also directly proportional to the load the differential efficiency of the gear is a constant quantity independent both of load and speed.

Preliminary Tests.

In response to the invitation of the British Electrical and Allied Manufacturers' Association eleven meter makers or their agents sent samples of the meter trains they use. Thirty trains in all were received made up as follows :—

Pointer dials...	3
Creep counter dials	13
Jump counter dials...	14

The greater number of the trains were intended for meters of 1 kilowatt capacity and under, so that in most cases the reducing gear had a large ratio, and any periodic variation in the resistance of the counters would necessarily be reduced to a very small value as measured on the rotor spindle.

As a preliminary each train was geared to a small hysteresis motor and run until the Units axle had made a sufficient number of revolutions to secure a good average measurement of resistance. During this test the torque applied by the motor was varied to suit the varying resistance of the train and any periodic variations that were not masked by the irregular friction which is inseparable from a train of gear wheels were duly noted and their magnitude recorded.

The hysteresis motor used for these tests can be driven at any speed up to about 160 r.p.m., and any measured torque can be applied from zero up to about 80 d.c. with a precision of about 0·2 d.c. at all parts of the range. The torque is governed solely by the strength of the rotating field and is absolutely independent of the speed until the synchronous speed is nearly approached. The rotor, which has a vertical spindle, weighs 6 grammes complete, and the bearing friction is about 0·4 d.c. The moment of inertia of the rotor is almost negligible and when running on a steady load a very small increase in resistance is sufficient to stop the machine in a few revolutions. This is an important matter in testing the friction of small mechanisms, because a motor which had any considerable inertia would easily overcome temporary increases in resistance, and hence the variation which it is intended to study would pass entirely unnoticed.

Of the 30 trains received 21 were intended for a worm drive from rotor to first axle and 9 were arranged for a spur gear drive ; these gears comprising no less than 13, and 6, different pitches respectively. To avoid the preparation of 13 worms and 6 pinions to fit on the rotor spindle the wheel on the first axle of each train was removed and a worm wheel or spur wheel specially prepared for the purpose was fitted in place of it. Corresponding with these two special wheels a worm and a spur pinion were prepared of suitable sizes to fit on the rotor spindle. The use of one worm gear and one spur gear for these tests had the incidental advantage that all the trains were tested under the same conditions as regards efficiency and friction of the gear between rotor and first axle, and as will be seen when the tests are analysed, these factors largely determine the friction of a meter train as measured on the rotor spindle. On the other hand, a disadvantage was that the worm gear had a higher gear ratio than the worm-driven trains were intended to have, on an average, and the spur gear was of a somewhat lower ratio than the average. This, however, merely involves a multiplication of the test figures by suitable factors in order to arrive at values which correspond with average practice.

The differential efficiency of each of the special gears was calculated from the dimensions, taking the coefficient of friction at 0·20. Each gear was then tested for efficiency by fixing its wheel on a suitable axle, to which measured resistances were applied by weights. The gear being driven by the hysteresis motor, torques were measured for a series of loads, and the differential efficiency worked out from the test figures. The special worm gear had a wheel of 90 teeth 1·84 cm. pitch diameter, and a single-thread worm 0·35 cm. diameter, the gear ratio being 90 to 1. The special spur gear had a wheel of 100 teeth 2·75 cm. pitch diameter and pinion of 20 teeth 0·55 cm. pitch diameter, the gear ratio being 5 to 1. The efficiencies were as follows :—

Special Gears for driving Meter Trains	Differential Efficiency	
	Calculated	Observed
Worm gear	$0·22_6$	$0·21_0$
Spur gear	$0·96_2$	$0·94_7$

The calculated efficiencies given here only take into account the tooth losses and worm losses. The observed values are very nearly on the same basis, the bearing losses resulting from the load having been almost negligibly small in these tests. The test figures are sufficient to show that both gears were as nearly perfect of their kind as such things can be. It must not be supposed that such high efficiencies are attainable in practice, even with equally well cut gears. When the wheels are transferred from testing axles, specially constructed to avoid friction, to the

* It would be a little more than 981 in Scotland, where gravity is somewhat greater than it is in England.

[illegible]

TABLE [illegible]

[illegible]

[illegible]			[illegible]				[illegible]		
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	[illegible]	—	[illegible]	[illegible]	[illegible]	—	[illegible]
[illegible]	—	[illegible]	[illegible]	—	[illegible]	[illegible]	[illegible]	—	[illegible]
			[illegible]	—	6·0	7·7	[illegible]	—	[illegible]
			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
			[illegible]	—	[illegible]	[illegible]	[illegible]	—	[illegible]
			[illegible]	—	[illegible]	[illegible]	[illegible]	—	[illegible]
			[illegible]	—	[illegible]	27·3	[illegible]	—	[illegible]
			[illegible]	—	[illegible]	[illegible]	[illegible]	—	[illegible]
			[illegible]	—	[illegible]	[illegible]	[illegible]	—	[illegible]
			[illegible]	—	[illegible]	[illegible]	27	—	5·2
			[illegible]	—	[illegible]	[illegible]	[illegible]	—	[illegible]
			[illegible]	—	[illegible]	[illegible]	[illegible]	—	[illegible]
Average		[illegible]	Average		[illegible]	[illegible]	Average		[illegible]

[illegible] however, there was evidence of something more than this. Train No. 18 occasionally ran in a very irregular manner [illegible] normal friction of 3·9 d.c. Train No. 27, which ran quite [illegible] 28 d.c. But these changes were clearly accidental, and although they were recurrent in both trains their occurrence did not coincide with the rising and falling of the [illegible] jumper device.

[illegible] ance caused by the periodic engagement of additional digit wheels was easily detected. In one or two trains the [illegible]

[illegible] weight; on the contrary, the energy so spent is considerable, but, as already stated, the trains were nearly all [illegible] insignificant amount as measured on the rotor spindle, and [illegible] masked by the ordinary irregular friction variations to which reference has already been made. The periodic [illegible]

[illegible] gear. The kind of register employed makes but [illegible] ence, the average resistance being 5 or 6 d.c. for [illegible] effect on the rotor, and in their case it was not because the [illegible]

purpose for which it was designed this counter has no rival. Coupled to a 1,000 h.p. marine engine the friction of a Harding counter is negligible, but when used as the register of an electric meter the inherent defect in the principle of the mechanism becomes only too apparent.

Analysis of Pointer Dial Trains.

These being simple trains of spur and worm gearing there should not be any periodic variations in resistance. In practice, however, such variations do sometimes occur as a result of a gear wheel being slightly out of truth and engaging its teeth too deeply during a part of each revolution. But defects of this kind are not common and are not the principal cause of changes in friction. It is the irregular variations that must be reckoned with, and these are all the more difficult to deal with because they not only vary widely in magnitude and occur at irregular intervals of time, but their duration is also a matter of extreme uncertainty. They are apt to occur more or less suddenly, and when the friction of a train has undergone this kind of change it may run at the new value for a few minutes or for many hours before a change takes place to a more normal friction.

The pointer trains received were too few in number to enable any useful deductions to be made by averaging the results of tests. A comparison of the observed friction with the friction estimated from the average weights on the axles and the diameters of the pivots agrees very well in the case of the spur-driven train No. 1, being 2·3 d.c. estimated friction as against 2·2 d.c. observed. But the two worm-driven trains Nos. 2 and 3 show a large discrepancy, namely about 4·7 d.c. estimated friction for each of them against an actual friction of about 8 d.c. This kind of discrepancy is bound to occur in individual cases, and inspection of No. 3 train rather suggested that the reducing gear might be at fault from want of care and cleanliness in assembling. The five registering axles of this train were therefore tested separately by fixing the special worm wheel on the first of them and disconnecting the reducing gear. Tested in this way it required a rotor torque of 4·0 d.c. to overcome the resistance of the worm gear plus that of the five axles. The ratio of the worm gear being 90 and its efficiency about 0·20 the friction at the first axle would be $4 \times 90 \times 0{\cdot}2 = 72$ d.c. Now the friction of a train of 5 geared axles, each having a friction of say m d.c. is :—

Friction of 5 axles (reckoned at the first axle)

$$= m\left(1 + \frac{1}{g\,e} + \frac{1}{g^2\,e^2} + \frac{1}{g^3\,e^3} + \frac{1}{g^4\,e^4}\right)$$

where g stands for the common gear ratio—10 in this case—and e is the differential efficiency. Reckoned from this formula, taking the average weight on each axle as 6 grammes and the average pivot diameter as 41 mils, the estimated friction of the 5 register axles is 71 d.c., which agrees remarkably well with the observed value 72 d.c. These registering wheels may therefore be accepted as being in good order, and as they were of quite good ordinary workmanship it will be useful to estimate what resistance such a pointer dial might be expected to have on the rotor of a 1 kilowatt meter, both for a worm drive and a spur drive. The necessary reducing gears are those shown in Figs. 1 and 2.

The meter will be supposed to run at 60 r.p.m. at full load, and hence the gear ratio from rotor to tenths axle will be 3,600, which will be made up of a worm gear of 60 to 1 and two spur gears of 6 to 1 and 10 to 1 ratios. To convert the worm drive into a spur drive, the first axle is rearranged in a vertical position and engaged with the rotor by means of the 6 to 1 gear. The worm gear is then used to connect the first and second axles. The friction in the two cases is given in Table 3, and in order to bring out the essential difference between the two drives the incidence of the friction of each axle in the reducing gear on the rotor axle is shown separately. The friction of the register at the tenths axle is taken at its measured value, namely 72 d.c.

Table 3.

Friction of the Different Members of a Pointer Train as reckoned on the Rotor of the Meter.

Part of Train	Axle	Friction at Rotor in d.c. Worm Drive	Friction at Rotor in d.c. Spur Drive
Reducing gear	First	5·000	0·294
,, ,,	Second	0·980	0·980
,, ,,	Third (tenths)		
Register	Units		
,,	Tens	0·138	0·138
,,	Hundreds		
,,	Thousands		
Total friction of train		6·1	1·4

It is at once evident that the difference in the friction of the two drives is due to the great difference in the friction of the first axle, according to whether it is horizontal or vertical. In the latter position the bearing friction can be so enormously reduced that its incidence on the rotor axle is also very largely reduced, notwithstanding the great difference between the ratio of the spur gear and that of the worm gear.

The figures given in Table 3 for the total friction afford a good indication of what the friction of a fairly well made and clean pointer train may be expected to be with a worm drive and a spur drive, and in what degree the different parts of the train contribute to the total. As the first two axles account for nearly all the friction it is clear that Table 3 may be taken to apply to any type of train, no matter what the registering devices may be, provided the periodic variations in the resistance of counter registers are not forgotten.

If the total resistance of a train at the rotor axle is multiplied by the first gear and efficiency factors, the total resistance of the train as reckoned at the first axle is arrived at, and a figure is obtained which may be fairly used to compare one train with another, apart from the gear from rotor to first axle. In Table 3 the friction of the worm drive being 6·1 d.c. and the gear 60 and efficiency 0·2, the resistance of the first axle would be $6{\cdot}1 \times 60 \times 0{\cdot}2 = 73$ d.c. The corresponding figure for the spur drive, taking an ordinary value for the efficiency of the spur

[illegible]

are not so small as they might be, they are representative of present practice and will form a good basis on which to calculate the percentage variations [illegible] mechanism, the friction of any ordinary train of wheelwork [illegible] variations of 10 or 20 per cent above and below the normal. [illegible] similar variations were noticed in the preliminary tests of all the trains. Variations of the same order of [illegible] are, in the writer's experience, inherent in rotating [illegible] and axles which are pivoted in the ordinary way and run without lubrication. With lubricated bearings the percentage changes of friction are apt to cover a much wider [illegible] friction is not to be obtained by [illegible] must vary to some extent with the load transmitted by the gearing, it will be assumed that the variations in friction are simply proportional to the load and that + or − 15 per cent of the average resistance of the train is an adequate allowance to make for them ; a rough estimate at best, but [illegible]

[illegible]

TABLE 4

[illegible]

[illegible] selves, may become important when they form an addition [illegible] the periodic variation of a counter [illegible] the period when the speed has fallen below the normal, the extent of the fall may vary between the limits 8·5 and [illegible] to or subtracted from [illegible]

[illegible] Harding counter, the wheels, pinions and frame all being [illegible] digit wheels arranged in line on a common axis, is gained at the expense of friction. Not only are the essential moving parts nearly doubled in number, but the axles are [illegible] wheel through [illegible] both receives the applied force and hands it on to the next wheel so that the maximum pressure is exerted on the pinion bearing and the maximum friction is created. [illegible] receive and transmit the load at [illegible]

The total resistance of a Harding counter when all the digit wheels are engaged and in motion may be ascertained in several ways. It may be deduced from the figures given in Table 2 by subtracting the torque required when only the first digit wheel is in motion, from the torque required to move all the wheels. The figures so obtained must be multiplied by the gear ratio of the train and the product of the several efficiencies of the series of reducing gears. Reckoned in this way the three Harding counters Nos. 6, 7, and 16 required, on an average, a torque of 537 d.c. to move all five digit wheels—that is to say, to set 4 nines to zero.

These three counters were identical in every respect, and the resistance of one of them was measured independently by disconnecting it from the reducing gear and applying a measured moment to the first digit wheel by means of a weight. The mean of half-a-dozen trials showed that it required a moment of 480 d.c to move all the wheels; it should be noted that this method is very apt to lead to an underestimate of friction because it is difficult to avoid more or less sudden applications of the weight.

In all experimental work on friction it is important to eliminate the chance of the mechanism under test being in an abnormal condition in consequence of some hidden defect, or the presence of dirt and dust in the bearings. The resistance of counter No. 16 was, therefore, calculated from the measured weights of the wheels and pinions, diameter of axles and coefficient of friction between the rotary elements and the axles; the assumption being made that all the parts were perfectly clean. If w is the bearing friction of a digit wheel, and p that of a pinion, the resistance of a 5-figure Harding counter when all the wheels are engaged is

$$w\left(1 + \frac{1}{e^2} + \frac{1}{e^4} + \frac{1}{e^6} + \frac{1}{e^8}\right) + gp\left(\frac{1}{e} + \frac{1}{e^3} + \frac{1}{e^5} + \frac{1}{e^7}\right).$$

where g is the gear ratio of wheel to pinion, and e is the differential efficiency, a quantity which can be estimated fairly closely for involute teeth running with no lubrication. Calculated from this formula the resistance of Harding counter No. 16 should be 503 d.c. when all the digit wheels are engaged, a figure which agrees sufficiently well with the experimental results to preclude the possibility of any abnormal friction being present in these three counters.

The remaining Harding counters were not analysed in this exhaustive way, but as they none of them differed materially from Nos. 6, 7, and 16, either in design or in dimensions, it will be useful to give their resistance as deduced from the preliminary tests given in Table 2. Reckoning each of the nine counters separately and then averaging, the mean resistance comes out at 585 d.c. when all the wheels are in motion.

The different results are set out in Table 5 for easy reference and comparison.

Experimental work on friction involves so many uncertainties and is liable to such disconcerting discrepancies, that the results of tests can only be accepted on cumulative evidence, such as that given in Table 5. It is clear that the little Harding counters, which are to-day in common use in electric meters, will require a torque somewhere between 500 and 600 d.c. when 4 nines are changing to zero, all the wheels being then engaged, this result being only true for counters which are new and perfectly clean. The bearings of a Harding counter are ill-adapted for ejecting dust and dirt, and a very small accumulation is enough to double or treble the friction. This is no reflection on the makers of the counters: all the Harding counters received for examination were very well made, and Nos. 6, 7, and 16 were wonderfully perfect both in design and workmanship.

TABLE 5.

Torque required on the first Digit Wheel of a 5-figure Harding Counter when 4 Nines are being changed to Zero, all the wheels being then in motion.

Method	Resistance, d.c.
Calculated from weights and dimensions of No. 16	503
Measured by weights applied to first digit wheel of No. 16	480
Deduced from rotor torque required to drive complete train; average for Nos. 6, 7, and 16	537
Deduced from rotor torque required to drive complete train; average for Nos. 4, 5, 8, 9, 10, 11, 12, 13, 14, and 15	585

TORQUE REQUIRED TO SET ANY NUMBER OF NINES TO ZERO, AND DECREASE OF SPEED DURING THE CHANGE.

If a 5-figure Harding counter requires a torque of 600 d.c. to set 4 nines to zero it does not follow that it will take 600/4 d.c. to move one digit wheel from 9 to 0. The equation already given for the resistance of a Harding counter shows that there is a geometrical cumulation of friction as the number of wheels engaged increases. The resistance of the counter when one, two, three, four, or five wheels are moving is shown in Table 6, which has been calculated on a maximum resistance of 600 d.c.

TABLE 6.

Resistance of Harding Counter reckoned at the first Digit Wheel.

Number of Nines being set to Zero	Total Resistance	Total Addition to Initial Resistance	Examples of the Change in the Dial Reading
None	28 d.c.	0 d.c.	23,715 to 23,716
One	93 ,,	65 ,,	23,719 ,, 23,720
Two	195 ,,	167 ,,	23,799 ,, 23,800
Three	354 ,,	326 ,,	23,999 ,, 24,000
Four	600 ,,	572 ,,	29,999 ,, 30,000

The first digit wheel is continuously in gear with the reducing train and its friction may therefore be reckoned with the ordinary train friction. Hence, in calculating the

[illegible]

TABLE [illegible]

[illegible]

Kw.	Digit wheel	10	50	100	10	50	100	[illegible]	[illegible]
1	1	5·4	1·27	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
	3	[illegible]	[illegible]	[illegible]	3·20	[illegible]	[illegible]		
	4	[illegible]	[illegible]	[illegible]	[illegible]	1·31	[illegible]		
2	1	[illegible]	[illegible]	[illegible]	0·32	[illegible]	[illegible]	[illegible]	[illegible]
	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
	3	13·6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
	4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
5	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
	3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
	4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
10	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0·01₆	[illegible]	0·04
	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
	3	[illegible]	[illegible]	0·32	[illegible]	[illegible]	[illegible]		
	4	4·77	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		

[illegible]

[illegible] used in meters of small capacity and hence the table is confined to 1 kilowatt and 10 kilowatt meters. It should be noted that more than half the creep counter trains had [illegible]

[illegible]

changed, 90 when three nines changed, and 10 when four nines changed. On each of these occasions the time occupied in making the change was longer than it would have been without the additional resistance; longer than the normal or correct time for registering one dial unit or step. The proportion between the actual time spent on a change, and the correct time, may be expressed as a factor k by which the correct time must be multiplied to arrive at the actual time, and if k_1, k_2, k_3, and k_4 are the factors corresponding to the changing of 1, 2, 3, and 4 nines, then the actual consumption during the nine-changing periods throughout a complete dial cycle is:—

$$9{,}000\,a\,k_1 + 900\,a\,k_2 + 90\,a\,k_3 + 10\,a\,k_4,\ \text{kw.-hours}$$

and the amount registered on the dial in respect of those periods will be 10,000 a, kw.-hours.

Here (as in the formula given on page 505) a stands for the Board of Trade Units (or fraction of a Unit) registered per movement or step of the first digit wheel. The factor k is the reciprocal of $1 - \frac{n\,W\,R}{600\,a\,c\,S\,T}$, and to find k_1, k_2, etc., it is only necessary to take the corresponding values of R from Table 6.

It will be seen that the under-registration depends on what the load happens to be during the nine-changing periods, and it is not affected by the load there may be at other times. Taking an unfavourable case—that of a 1 kilowatt meter of 1 grm. cm. torque and 10 r.p.m. full-load speed, with a Harding counter which has a maximum resistance of 600 d.c. and has the first digit wheel on the hundredths axle so that $a = 0{\cdot}01$, the loss during a complete dial cycle would be as follows:—

At 1/5th full load	3·4 units lost in	1,000	= 0·34	per cent
„ 1/10th „	7·0 „	„	= 0·70	„
„ 1/20th „	17·5 „	„	= 1·75	„

These figures suggest that if the meter were standardized to run about ¾ per cent fast the loss from nine-changing would be made good, so long as the counter retained its initial friction.

Analysis of Jump Counters.

The jump counter presents a much simpler problem than the creep counter. It is only necessary to measure the maximum moment of the weight or spring which is used to propel the digit wheels, and the periodic speed variations are then merely a matter of arithmetic.

All the jump counters, except one, were of the type in which a weight is lifted and then made to propel the counter during its fall. It was obvious from inspection that there was no material difference in the weight used in the different counters, and a measurement of one of them, taken from a typical jump counter, showed that it had a maximum moment of about 1,000 d.c. This is the moment provided for the purpose of overcoming the additional friction of the counter when all the digit wheels are engaged. To ascertain what the additional friction might be, the total friction and the friction of the first digit wheel were both measured by the falling weight method, and also estimated from the weights of the moving parts and the diameter of the pivots. The counter just referred to was chosen for this comparison, and the measured and estimated amounts were as follows:—

Friction of 4-figure scallop-wheel Jump Counter.

	Estimated d.c.	Measured d.c
Total friction with all digit wheels engaged	392	450
Friction of first digit wheel	116	195
Friction to be overcome by jumper weight	276	255

From these figures it may be safely assumed that apart from accidental additions to friction this counter requires about 300 d.c. additional driving torque when all the digit wheels are to be set in motion. The torque provided by the jumper weight being about 1,000 d.c. there is evidently an ample margin, especially as the weight falls suddenly and the digit wheels are therefore started by impact.

In nearly all jump counters the work done in lifting the jumper weight is spread over the whole revolution of the axle on which the jump device is fitted, by the use of a counterweight as described in the appendix and illustrated in Fig. 6. By this ingenious expedient the maximum torque required to lift the jumper weight is reduced by one-half, and hence the maximum resultant moment to be taken as a basis in calculating the periodic speed variation will be 500 d.c. The moment at any angular position of the resultant weight will be 500 sin θ, and since the mean value of sin θ is $2/\pi = 0{\cdot}636$, the mean resultant moment will be $500 \times 0{\cdot}636 = 318$ d.c., the maximum being 500 and the minium zero of course. That is to say, the extreme variations on either side of the mean are unequal, being 182 d.c. above the mean and 318 d.c. below it. These unequal variations of moment cancel out in the course of one complete revolution of the axle on which the jump device is fitted, the larger variation lasting for the shorter time of course. The difference between the variations below and above the mean moment being so considerable, the corresponding increase and decrease in speed is given separately in the table of speed variations for jump counters.

The greater number of the jump counters received for examination had the jumper device on the units axle, and with this arrangement only the tens, hundreds, and thousands digits jump from one to the next. The digits in the units place creep from one to the next because in this case the units axle is driven continuously by the reducing gear. The dial opening is generally wide enough to allow the following digit to be seen before the leading digit disappears, and when two are visible at once the human nature of the meter reader determines which is the proper figure to take. It should be noted that at a time when the jumper weight is about to fall and so register another ten Units on the tens axle, the digit nine in the units opening will have disappeared and zero will have crept into its place preparatory to the impending change in the tens digit. Here would be a real ambiguity if it were not provided for by

[illegible]

TABLE 8.—[illegible]

[illegible]

Percentage of Jumper Load		10	50	100	10	50	100	Average percentage [illegible]	[illegible]
		Percentage Change in Speed at [illegible]			Percentage Change in Speed at [illegible]			[illegible]	[illegible]
1	fast	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1·2	[illegible]
	slow	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	fast	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	slow	[illegible]	[illegible]	0·01	[illegible]	[illegible]	[illegible]	[illegible]	0·2
5	fast	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0·07	[illegible]	[illegible]
	slow	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10	fast	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	slow	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TABLE 9.—100-KW. METER WITH JUMP CONTROL.

Periodic Speed-changes above and below the Normal Speed when the Meter is running at [illegible] of Full Load.

[illegible]		50	100	50	100	[illegible]	[illegible]
		Percentage change in speed [illegible]		Percentage change in speed [illegible]		[illegible]	[illegible]
2	fast	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	slow	[illegible]	0·89	[illegible]	[illegible]	[illegible]	[illegible]
5	fast	1·25	0·62	[illegible]	[illegible]	[illegible]	[illegible]
	slow	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10	fast	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	slow	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
20	fast	[illegible]	0·10	[illegible]	[illegible]	[illegible]	[illegible]
	slow	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible] from view until the falling of the weight has driven the [illegible] one step forward. Another and in some respects better arrangement is to remove the digits [illegible] and [illegible] from the units digit wheel by cutting away a corresponding sector of that wheel. A subsidiary figure disc fixed to and moving with the jumper device, has the [illegible]

[illegible]

When the jumper device is on the [illegible]

significant digits from units upwards are actuated by the weight and no shutter or auxiliary figure disc is required. It is to be regretted that this arrangement is not always possible.

Table 8 gives the speed changes for jump counters for meters of 1 and 10 kilowatt capacity, and Table 9 gives the corresponding figures for a 100 kilowatt meter. In this case it has been assumed that so large a meter would not be designed for a torque below 2 grm. cm., and as such a meter might well have a torque in excess of 10 grm. cm. the speed changes are given for a torque of 20 grm. cm. Figures are included for the case of a jump counter with the jump device on the tens axle, a position which is sometimes rendered necessary by the low ratio of the reducing gear in meters of large capacity.

It will be remembered that the preliminary tests of jump counter trains for meters of 1 kilowatt and under, showed no periodic variations in resistance which could be traced definitely to the rising and falling jumper weights. Table 8 makes the reason clear: the incidence of the register resistance on the rotor spindle was so small that the periodic effect would inevitably pass unnoticed when confused, as it

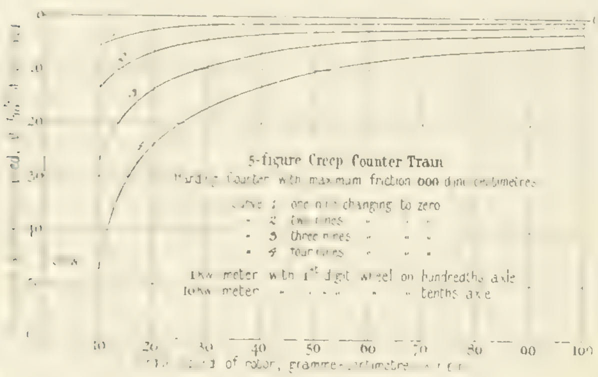


FIG. 3.

was, with the speed changes due to irregular friction. The actual change in resistance caused by the jumper weights, is reckoned on the rotor axle, in no case exceeded 0·3 d.c. above and below the normal, and although such a resistance is well within the scope of the hysteresis motor, provided frictional resistance is constant, it was of course swamped by the irregular friction changes which occurred throughout these tests.

Inspection of the figures in the tables of speed variation suggests at once that, so far as the resistance of the register of a meter train is concerned, the percentage speed-changes depend largely on the product of torque and speed. So much was of course obvious from the outset, because the speed variation resulting from any change in resisting moment must be limited by the mechanical power of the meter—its power as an electric motor—and the torque-speed product is a measure of that power. But it was not possible to foresee to what extent the magnitude of the variations would be affected by the necessary changes in the reducing gears (and their efficiencies) which are required to adapt a train for meters having different speeds at full load. For this reason speeds and torques have been dealt with throughout as separate factors.

It should be noted that in preparing the tables the simplest possible combination of gears has been taken to make up each reducing gear to the required ratio. No allowance has been made for the introduction of additional axles for change wheels or idle wheels such as are

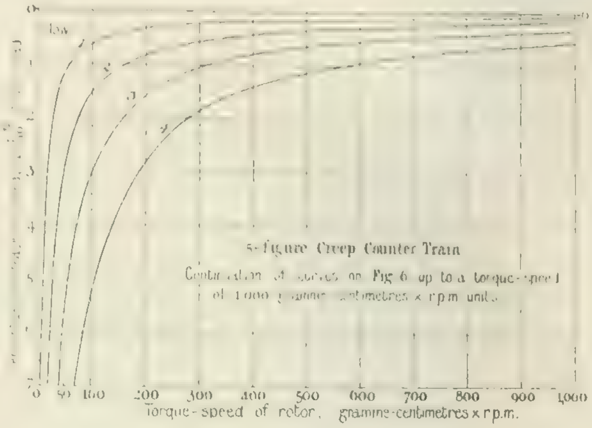


FIG. 4.

frequently required in a train to adapt it for a particular meter. Hence the figures in the tables are the variations which would occur under the most favourable conditions as regards the efficiency of the reducing gear as a whole.

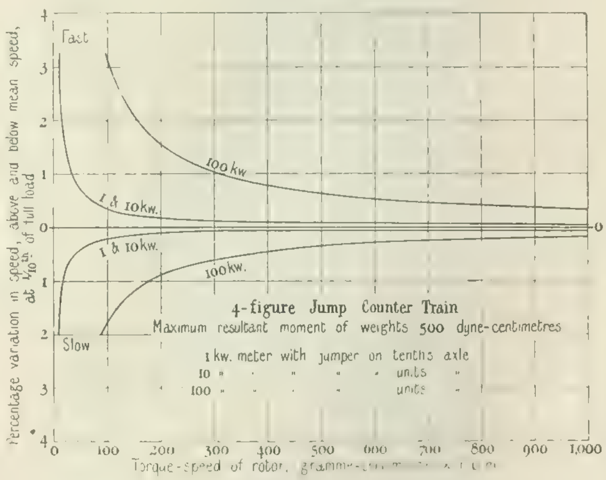


FIG. 5.

Worm gear has been taken at an average efficiency of 0·2, and spur gear at an average of 0·85, both figures being derived from experiments on trains of reducing gear. It must not be forgotten that the tables are based on the resistance of new counters in a fairly clean condition.

SPEED VARIATIONS IN TERMS OF THE MECHANICAL POWER OF THE METER, AS MEASURED BY TORQUE-SPEED.

Although the speed variations for meters of different full load speeds are in many cases affected by the alteration in efficiency due to changes in the reducing gear, it is quite

[illegible]

are common to all meter trains, no matter what the [illegible] are small, but at one-tenth load and with a worm drive [illegible]

[illegible] long as the first digit wheel is indicating any digit from [illegible]

[illegible] adjustment of meters

[illegible] wheel at three [illegible] by the centre of the dial opening, [illegible]

[illegible] caused the digits to [illegible]

doubt that in one form or another the latter will ultimately take the place of the creep counter. The designer of meter trains is not confined to any one type of discontinuous gear for the counter; there are half-a-dozen kinds well adapted for the purpose, and the time will surely come when all meter counters, whatever the mechanism may be, will be provided with some simple means for securing instantaneous movement of the digit wheels.

Apart from the universal employment of a jump device, there is still room for improvement in the construction of direct-acting counters. Generally speaking the moving parts are quite needlessly heavy. Their weight, and therefore their friction, might easily be halved without in any way adding to manufacturing difficulties. In this respect the makers of direct-action counters might take the little Harding counters as a guide, for there we find not a grain of superfluous metal in any of the moving elements. Again, as regards pivots and bearings, ordinary engineering practice is in many instances followed too closely. Long parallel bearings, which are essential when lubrication is to be used, are quite out of place in a meter train, where it is essential to avoid dust traps. Attention to the design of pivots and bearings, particularly those of the first and second axles, will not only largely reduce friction, but also greatly lessen the irregular variations. Upon the whole the gears are well cut and set to run with sufficient back-lash, but here and there teeth of those fantastic shapes beloved by old-fashioned clockmakers are still to be found. Several trains, otherwise well designed, had gears of an exceedingly fine pitch—far too small for high efficiency. Spur gears having well-cut involute teeth, with a pitch round about 1 mm., give a tooth efficiency of 95 per cent and have the additional advantage of providing fewer dust traps than the gears of fine pitch.

Meter trains are so easily capable of improvement in all these matters of detail that the time may well come when the small remaining frictional and periodic variations in resistance will pass out of the region of effects which cannot be ignored and cease to be of any practical importance.

APPENDIX.

Counter Gears and the Jump Device.

All counter gears are based on the principle of a driving wheel with one tooth engaging once in each revolution with a 10-toothed wheel of the same pitch diameter. The engagement lasts for one-tenth of a revolution, and during the remaining nine-tenths the driven wheel must be prevented from moving by some kind of lock. The only locking devices which are free from objection on mechanical grounds are those in which the driven wheel is locked by a moving piece fixed on the driving axle, and so arranged that during the locked period it occupies space through which the teeth of the driven wheel must necessarily pass during rotation. Three typical examples of such gear are shown in Figs. 6, 7, and 8. In all these figures A is the driving axle and B the driven one.

In Fig. 6 the 10-toothed scallop wheel S_1 is locked by the edge of the locking disc L, except when the notch N by passing into the region of engagement permits S_1 to rotate. But the notch is unable by itself to engage with a tooth on the scallop wheel. To effect this a second 10-toothed wheel S_2 is fixed on the axle B a little distance behind S_1. The teeth of S_1 and S_2 being staggered, the latter will have one tooth in the path of the pins T, T, which project from the back of the locking disc; hence at the proper time the

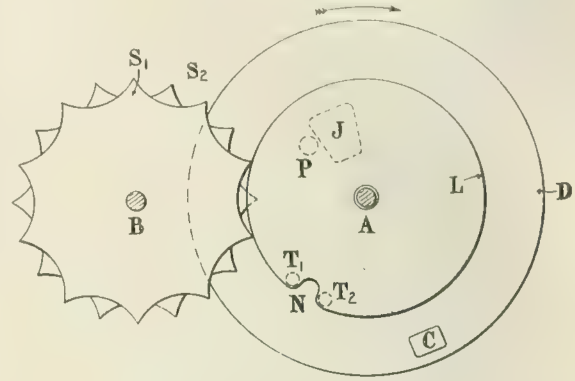


FIG. 6.—Scallop-wheel Counter Gear and Jump Device.

leading pin will impinge on this tooth and by moving it on will cause the adjacent following tooth on S_1 to enter the notch. In this way the two axles are brought into gear, and they remain in gear until first the pin and then the notch disengage themselves, and the scallop wheel S_1 is once more locked; axle B having been moved through exactly one-tenth of a revolution. The following pin plays

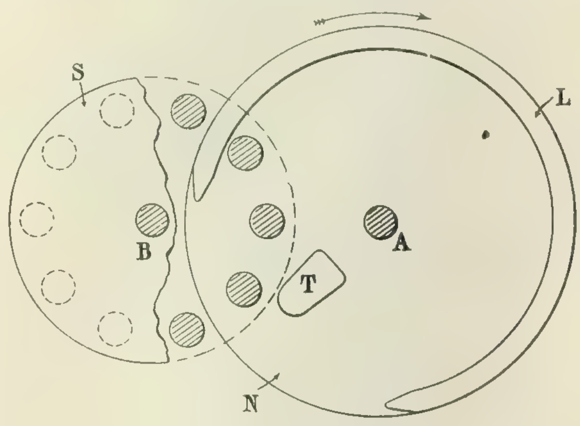
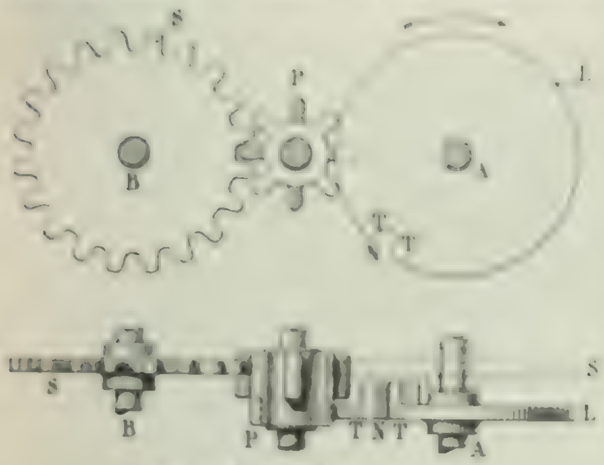


FIG. 7.—Evershed Counter Gear.

no part in this engagement, but it is brought into use if the direction of rotation is reversed, when it becomes the leading pin. This second pin was omitted in one of the counters received for examination, and consequently if the meter were driven backwards the counter gear would jamb. The second pin is essential if a reversible counter is required.

In Fig. 7, a counter in which the writer has a fatherly interest, the driven element takes the form of a crown wheel, and the locking is done by a ring L which passes between the teeth or pins of the crown wheel. The crown wheel is driven solely by the single tooth T, the locking

[illegible]



[illegible]

[illegible] time, and hence there are two teeth T, T, on the driving element to engage with the pinion. Since the pinion is [illegible] to give it eight teeth, so that it may rotate through one-quarter of a revolution at each engagement. At the interlocking end of the pinion alternate teeth are removed leaving four teeth at right angles to act as the locking members. For explanatory purposes the driving and driven elements of the Harding counter have been shown [illegible] but it is obvious that the spur wheel [illegible] in any position round the pinion. In [illegible]

[illegible]

THE [illegible]

[illegible] the axle and naturally rests with J at [illegible] the jumper weight and carries it and the element L round with it, gradually raising the weight from its lowest position until after half a revolution of the digit wheel the weight [illegible] weight then remains at rest in the lowest position until the [illegible] the pin P once more into contact with it. The work done in lifting the jumper weight is spread over a whole revolution of the digit wheel by the addition of a counterweight [illegible] to be done is equally divided between the two halves of each revolution of the axle A, and the maximum torque required in the process of weight-lifting is reduced to one-half the maximum moment of the jumper weight. In meters of large capacity it is important that the two weights [illegible]

DIMENSIONS OF TRANSFORMERS.

By A. R. Low, Associate Member.

(*Paper first received 20 May, 1914, and in final form 25 January, 1915.*)

1. In Volume 43 of the *Journal* the author contributed a paper on the above subject, which was limited to the particular cases of single-phase core and shell transformers of uniform rectangular cross-section.

On page 232 of that volume a bibliographical list was given of 13 papers or articles which had appeared in the technical Press, dealing with particular cases of the general problem. Professor Robertson, in Bohle and Robertson's "A Treatise on Transformers" (1910), cites the bibliography, but no writer appears to have referred to the results obtained in the above paper.

At the end of the present paper, the list is reprinted with 10 additional references, bringing the bibliography nearly up to date. A number of minor papers are omitted as containing no new or important developments.

In the 1909 paper a graphical method was developed which showed how the minimum volumes, costs, or losses were approached. In this paper a more powerful method is developed which proceeds directly to the "best" dimensions, but which loses the advantages of graphical representation. In the 1909 paper approximate formulæ were given for the dimensions, which involved only multiplication, division, and root extraction.

Rigorous solutions are given below for the same problems, requiring the solution of a quintic and a cubic equation. Both methods offer interesting applications of the theory of maximum and minimum values of algebraic functions of several variables.

The author has not seen elsewhere the convenient matrix form of the equations of condition for "turning values" obtained by eliminating Lagrange's indeterminate multipliers.

Professor Robertson's "Mathematical Theory of Transformer Design" † is criticized at some length, and errors in principle are pointed out which are unfortunately characteristic of the whole literature of the subject both with English and with German writers.

Geometrical Restriction Imposed by Assuming Special Shapes.

2. Nothing was said in the 1909 paper about the initial assumption of uniform rectangular cross-section for both circuits. This assumption imposes geometrical restrictions of a far-reaching character; for let us suppose that all considerations of manufacturing convenience are removed and that the circuits may pass continuously from the standard form to the geometrically best form. If we start with a core type, this flux of form will take place so that the product of the cross-sections remains constant while the mean lengths of the circuits shrink. The copper will distribute itself uniformly round the core instead of being concentrated on the two limbs, so as to reduce the depth of winding and thereby the mean length of turn. The core itself will assume a figure of revolution about an axis, for, where symmetry about an axis is possible, the volume of revolution has least cubic content for a given product of the cross-sections. The whole arrangement will assume approximately the shape of an orange (see Fig. 1). Sections perpendicular to the axis will show circular boundaries.

3. Sections parallel to the axis will show that the core section is not circular. For it is easy to see that flattening out the core section reduces the mean iron length, while the rate of change of the perimeter, on which the mean

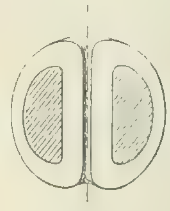


Fig. 1.

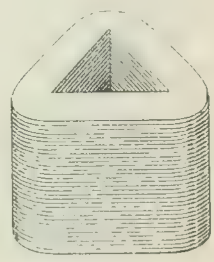


Fig. 2.

copper length depends, is zero for the circular form. Thus the flattening-out must proceed some appreciable distance before the rate of increase of the copper length outweighs the reduction of the iron length. To determine the equations of the boundary curves under these most general conditions would require the resources of the calculus of variations.

4. If now we limit ourselves to uniform stampings, these will always be built up into a right prism; for building obliquely would increase the copper length while reducing the copper section. The general shape of the stampings may be triangular, quadrangular, or polygonal. In these cases the internal boundary will be a triangle, quadrilateral, or polygon. The external boundary will be triangular, quadrangular, or polygonal, with the corners rounded off by arcs of circles.

Calling the opening in the stamping the "window," considerations of symmetry impose a regular form on the polygon which forms the boundary of the window. The triangular window must be equilateral (see Fig. 2), the quadrangular window square, and the polygonal window a regular polygon, or in the limit circular. The symmetry is trilateral, quadrilateral, or multilateral according to the case. The ordinary core transformer, with windings on two limbs only, does not come under the above classification. It has only bilateral symmetry about an axis, and

* A. R. Low. Dimensions of single-phase core and shell transformers, with copper and iron circuits of uniform rectangular cross-section. *Journal I.E.E.*, vol. 43, p. 217, 1909.

† Chapter X of the Treatise reprinted.

[illegible]

7. On [illegible]

[illegible] stampings. If we interchange core and coils in the last case, we get an approximation to the well-known Berry [illegible] there is a large variety of assumptions possible, according to the different manufacturing limitations imposed, yet the [illegible]

[illegible]

[illegible] but it is sufficiently accurate to assign them completely to the coils and to take the external edges and faces of the core as the overall boundaries of the iron circuit, and the opening in the core or the window as the overall cross-section of the copper circuit. By the application of [illegible] to Figs. 3 and 4, we may [illegible] pendently without departing from the condition that both [illegible] assumption that the core is square is equivalent to the [illegible]

[illegible]

[illegible]

[illegible]

Calling the ratio of net metal cross-section to gross [illegible]

[illegible]

[illegible] as constant, and if the design so [illegible]

The values of n and m for uniform distribution of metal through the circuit are $\pi/2$ and $\pi/4$. In practice the low-tension coils are often next the core, and the copper is thus concentrated near the inside of the coil. In such a case we may take m as $\pi/5$. This gives $m \times n = 0{\cdot}99$. When $m \times n$ is unity an important simplification of the results takes place, and when $m \times n$ is within 20 or 30 per cent of unity, good approximate values may be obtained in this simpler form.*

11. The volumes of the circuits are the products of the cross-sections by the mean lengths.

$$
\begin{aligned}
\text{Gross iron volume} &= 2\,y\,u\,(z + x + n\,y),\\
\text{Net} \quad \text{,,} \quad \text{,,} &= 2\,f_i\,.\,y\,u\,(z + x + n\,y),\\
\text{Gross copper volume} &= 2\,x\,z\,(u + y + m\,x),\\
\text{Net} \quad \text{,,} \quad \text{,,} &= 2\,f_c \times x\,z\,(u + y + m\,x).
\end{aligned}
$$

For brevity we may put

$$
\begin{aligned}
A &= y\,u\,(z + x + n\,y),\\
B &= x\,z\,(u + y + m\,x).
\end{aligned}
$$

and later we shall write

$$
\begin{aligned}
Z &= z + x + n\,y,\\
U &= u + y + m\,x,
\end{aligned}
$$

so that

A and B are half the gross volumes,
Z and U are half the mean circuit lengths.

12. The specific mass of iron is about 7·7 kilograms per cubic decimetre and of copper about 8·9.

$$
\begin{aligned}
\text{Total mass of iron} &= 2 \times 7{\cdot}7 \times f_i\,A\ \text{kg}.\\
\text{Total mass of copper} &= 2 \times 8{\cdot}9 \times f_c\,B\ \text{kg}.
\end{aligned}
$$

13. There are known expressions for the losses in the iron and copper when the flux and current densities, temperature, frequency, and degree of lamination are known. These are of the form

$$
\begin{aligned}
\text{Iron loss} \quad \text{per kg.} &= a\,\mu^{1\cdot6} + b\,\mu^2,\\
\text{Copper loss} \quad \text{,,} &= c\,\nu^2,
\end{aligned}
$$

where $\mu = \mathbf{B} \times 10^{-4} =$ flux lines per sq. cm. $\div 10^4$,
$\nu =$ ampere lines per sq. cm. $\div 10^2$.

The losses per cubic decimetre gross are

Iron loss per cubic dcm. gross

$$= 7{\cdot}7 \times f_i\,(a\,\mu^{1\cdot6} + b\,\mu^2) = \tfrac{1}{2}\,g_i \text{ say,}$$

Copper loss per cubic dcm. gross

$$= 8{\cdot}9 \times f_c \times c\,\nu^2 = \tfrac{1}{2}\,g_c \text{ say.}$$

Observing that g_i, g_c so defined are twice the losses per cubic decimetre gross, and recalling that A and B are half gross volumes we get

$$
\begin{aligned}
\text{Total iron loss} &= g_i\,A,\\
\text{Total copper loss} &= g_c\,B.
\end{aligned}
$$

a, b, c, are coefficients determined by experiment and corrected by calculation for various conditions of temperature rise, frequency, thickness of laminations, etc.

For "Stalloy" sheets 0·02 in. thick and electrolytic copper of medium section at 50 periods per second and 120° F., we may put approximately as average values

$$a = 1{\cdot}7\,; \quad b = 0{\cdot}5\,; \quad c = 2{\cdot}2.$$

Each designer should determine these average values by experiment for himself.

14. If we assume that the core and coils are rated up to the permissible limits of saturation and temperature rise, μ and ν may vary slowly for a range of designs of equal output under similar conditions, and may be assumed constant as a first approximation.

We may take $\mathbf{B} = 14{,}000$, or $\mu = 1{\cdot}4$, as the upper limit at 50 periods per second or less, while ν ranges from 3 ampere-lines per square millimetre in small transformers down to 1·5 in larger transformers. Wider ranges of ν no doubt occur, and for higher frequencies $\mathbf{B}$ is restricted by the temperature rise.

15. In the above equations it is assumed that the flux is uniformly distributed in the core. This is only approximately true, but the difference in losses given by this assumption is found in practice to be of little importance, especially in comparing similar types of transformer.

The current density is sometimes greater in the low-tension than in the high-tension coils, sometimes less. An average value giving the same total losses may be assumed from one type and applied to a range of designs without much error. We thus find that the space factors and densities are only approximately constant and that the flux and current densities are by no means uniform. In addition, the temperature rise and reactance pressure-drop may exceed the specified limits when the dimensions are varied in the direction of least losses or costs. It may seem a formidable task to introduce corrections for all these quantities, but in practice a little experience enables the designer to manœuvre them all in various directions until a fair compromise is attained. Undoubtedly the apparently "rough and ready" nature of these assumptions has prevented professional mathematical physicists from studying the problem of transformer dimensions. At the same time the mathematical analysis required, even after all these simplifying assumptions have been made, has proved sufficiently hard to defeat the engineers who have attacked the problem. Only an experienced designer can employ the method developed here usefully, but used with discretion it cuts out an exceedingly large amount of "trial and error" design. It is also capable of giving a really comprehensive outlook to an adequately-equipped technical student.

16. If l_i, l_c are the costs per kilogram of iron and copper we obtain two coefficients k_i, k_c which are twice the costs per cubic decimetre of gross volume of the circuits.

$$
\begin{aligned}
k_i &= 2 \times 7{\cdot}7 \times f_i\,l_i,\\
k_c &= 2 \times 8{\cdot}9 \times f_c\,l_c.
\end{aligned}
$$

Expressions for iron and copper costs (active material only) are

$$
\begin{aligned}
\text{Cost of iron core} &= k_i\,A,\\
\text{Cost of copper core} &= k_c\,B.
\end{aligned}
$$

If we introduce I, J, for the total iron and copper losses and costs, we have

$$
\begin{aligned}
I &= g_i\,A + g_c\,B,\\
J &= k_i\,A + k_c\,B.
\end{aligned}
$$

* The symbols m and n of this paper correspond to the symbols $1 \div m''$ and m' of the 1906 paper.

[illegible]

$$\Phi = [illegible]$$
$$\mathfrak{J} = [illegible]$$

[illegible]

$$P = P_1 \text{ a constant} \qquad (1)$$

[illegible]

18. Subject to this relation we may desire to find the dimension corresponding to minimum losses, I, or to [illegible] costs, J.

[illegible]

$$\frac{\partial I}{\partial x}\delta x + \frac{\partial I}{\partial y}\delta y + \frac{\partial I}{\partial z}\delta z + \frac{\partial I}{\partial w}\delta w = 0$$

and since $P = P_1$ a constant we have

$$\frac{\partial P}{\partial x}\delta x + \frac{\partial P}{\partial y}\delta y + \frac{\partial P}{\partial z}\delta z + \frac{\partial P}{\partial w}\delta w = 0.$$

Using Lagrange's method [illegible]

[illegible]

Since there is only one relation (1) between the four variables we may consider any three variables independent. [illegible] $\frac{\partial I}{\partial w} + \lambda\frac{\partial P}{\partial w}$ [illegible] $\lambda = -\frac{\partial I}{\partial w}\Big/\frac{\partial P}{\partial w}$

[illegible]

[illegible] minant, the vanishing of which gives a relation between the variables necessary for a stationary value of I when P is constant. The advantage of the matrix notation is that we may use the rules for the reduction of matrices.

Only three of the relations so obtained are independent. [illegible]

[illegible] the conditions would have been similar, with J's substituted for I's in the matrix.

[illegible] systems are evidently equivalent.

[illegible] minimum costs we have I and J sim[illegible] but

[illegible]

Hence equivalent conditions are that A and B should be [illegible]

[illegible]

[illegible] adding the sum to the third

[illegible]

Then since there is only one relation (1) between the [illegible]

we may choose any two, say x and y, as independent, and since λ_1, λ_2 are arbitrary we may choose them so that the coefficients of δz and δu vanish identically.

This enables us to adopt any one other arbitrary relation between x, y, z, and u, consistently with $P = P_0$ and with the two independent conditions contained in the matrix below. Hence as the condition for "turning values" the coefficients of δx, δy must also vanish for all values of δx and δy. This gives us, on eliminating λ_1 and λ_2,

$$\left\| \begin{array}{ccc} \frac{\partial A}{\partial x}, & \frac{\partial B}{\partial x}, & \frac{\partial P}{\partial x} \\ \frac{\partial A}{\partial y}, & \frac{\partial B}{\partial y}, & \frac{\partial P}{\partial y} \\ \frac{\partial A}{\partial z}, & \frac{\partial B}{\partial z}, & \frac{\partial P}{\partial z} \\ \frac{\partial A}{\partial u}, & \frac{\partial B}{\partial u}, & \frac{\partial P}{\partial u} \end{array} \right\| = 0.$$

This contains only two independent conditions. Combining these with $P = P_0$ we have three relations between four variables, giving a one-fold infinity of solutions as in the 1909 paper.

21. Substituting the values of A, B, P, and their derivatives, we may multiply the first row by x, the second by y, the third by z, and the fourth by u. Adding together all the rows we get a fifth row, the terms of which are $3A$, $3B$, $4P$, a result which at once follows from Euler's theorem for the partial differential coefficients of homogeneous functions.

$$\left\| \begin{array}{ccc} x\frac{\partial A}{\partial x}, & x\frac{\partial B}{\partial x}, & x\frac{\partial P}{\partial x} \\ y\frac{\partial A}{\partial y}, & y\frac{\partial B}{\partial y}, & y\frac{\partial P}{\partial y} \\ z\frac{\partial A}{\partial z}, & z\frac{\partial B}{\partial z}, & z\frac{\partial P}{\partial z} \\ u\frac{\partial A}{\partial u}, & u\frac{\partial B}{\partial u}, & u\frac{\partial P}{\partial u} \\ 3A, & 3B, & 4P \end{array} \right\| = 0.$$

Dividing the first column by $y u$, the second by $x z$, and the third by P we get

$$\left\| \begin{array}{lll} x & , \; u + x + 2mx & , \; 1 \\ z + x + 2ny & , \; y & , \; 1 \\ z & , \; u + y + mx & , \; 1 \\ z + x + ny & , \; u & , \; 1 \\ 3(z + x + ny) & , \; 3(u + y + mx) & , \; 4 \end{array} \right\| = 0,$$

whence by successive reductions

$$\left\| \begin{array}{lll} z - x & , \; -mx & , \; 0 \\ -ny & , \; u - y & , \; 0 \\ x + ny & , \; -(y + mx) & , \; 0 \\ 3(z + x + ny) & , \; 3(u + y + mx) & , \; 4 \end{array} \right\| = 0,$$

giving
$$\frac{y + mx}{x + ny} = \frac{mx}{z - x} = \frac{u - y}{ny},$$

whence
$$z = x\,\frac{(1 + mn)\,y + 2mx}{y + mx} \quad . \quad . \quad . \quad . \quad . \quad (5)$$

$$u = y\,\frac{(1 + mn)\,x + 2ny}{x + ny} \quad . \quad . \quad . \quad . \quad . \quad (6)$$

Both these results were obtained in the 1909 paper.

22. If we assume as in the 1909 paper that the iron and copper losses are in a given ratio, we have, using the expressions in §§ 11 and 13,

$$\frac{g_i \times y u (z + x + n y)}{g_c \times x z (u + y + m x)} = \text{given ratio},$$

or
$$\frac{y u (z + x + n y)}{x z (u + y + m x)} = \frac{g_c}{g_i} \times \text{given ratio},$$
$$= s \text{ say}.$$

This may be taken as the new arbitrary relation permissible as stated in § 20.

If we substitute values of z and u from (5) and (6) in the above we get

$$\frac{y^2}{x^2} \times \frac{(1 + mn)\,x + 2ny}{(1 + mn)\,y + 2mx}$$
$$\times \frac{x\,[(1 + mn)\,y + 2mx] + (x + ny)(y + mx)}{y\,[(1 + mn)\,x + 2ny] + (y + mx)(x + ny)} = s.$$

This is homogeneous in y and x. Putting $y/x = l$ we get a quintic in l

$$2n^2 l^5 + 5n(1 + mn)l^4 + [2(1 + mn)^2 + 6mn - 3sn(1 + mn)]l^3$$
$$+ [3m(1 + mn) - \{2(1 + mn)^2 + 6mn\}s]\,l^2$$
$$-5m(1 + mn)sl - 2m^2 s = 0 \quad . \quad . \quad . \quad (7)$$

If $mn = 1$ this reduces to a cubic

$$ny^3 + 3xy^2 - 3sx^2y - msx^3 = 0 \quad . \quad . \quad . \quad (8)$$

23. If we take the data of the problem, in Section 19 page 231 of the 1909 paper we have

$$\mu = 1, \qquad \nu = 1, \qquad P_0 = 40{\cdot}5 \text{ k.v.a.},$$
$$g_i = 27{\cdot}6, \quad g_c = 13{\cdot}8, \quad g_i A : g_c B = 0{\cdot}4.$$
$$t_i = 0{\cdot}9, \qquad t = 0{\cdot}35, \quad m = \frac{\pi}{4}, \quad n = \frac{\pi}{2}.$$

Applying the methods of this paper, Equation (7) becomes

$$l^5 + 3{\cdot}56\,l^4 + 3{\cdot}1\,l^3 + 0{\cdot}356\,l^2 - 0{\cdot}358\,l - 0{\cdot}05 = 0.$$

The useful root is found by Horner's method* to be $l = 0{\cdot}307$. Equation (8) which is equivalent to the graphical method of the 1909 paper becomes

$$l^3 + 1{\cdot}91\,l^2 - 0{\cdot}382\,l - 0{\cdot}1 = 0.$$

The useful root is found by Horner's method to be $l = 0{\cdot}315$. On page 232 of the 1909 paper we find by the graphical method

$$x = 2{\cdot}28, \quad y = 0{\cdot}725,$$

whence $l = y/x = 0{\cdot}315$, which agrees with the approximate cubic. Tabulating the values obtained by the accurate

* Chrystal's "Algebra," vol. i, p. 341.

[illegible]

These [illegible] which are [illegible] the equations (5) and (6).

[illegible]

The useful root is found by Horner's method to be $l=0{\cdot}603$. The approximate value given by the assumption $m:n=1$, $z=2x$, $u=2y$, is

$$l=\sqrt[4]{\frac{m}{n}\times\frac{g}{g_i}}=0{\cdot}604.$$

Putting $l=0{\cdot}604$ in (5) and (6) we get the second approximation for x, y, z, u,

$$z=2{\cdot}10\,x,\qquad u=2{\cdot}12\,y,$$

putting these values in (10)

$$x^4=0{\cdot}788, \text{ whence in turn}$$
$$x=1{\cdot}075 \text{ dem.}\qquad z=3{\cdot}52 \text{ dem.}$$
$$y=1{\cdot}011 \;\;,,\qquad u=2{\cdot}142 \;\;,,$$

Tabulating the values given by the accurate method against those given by the first and second approximations of the 1900 paper we get :—

	Accurate	2nd Approx.	1st Approx.
x	1·68 dcm.	1·68 dcm.	1·72 dcm.
y	1·01 ,,	1·01 ,,	1·04 ,,
z	3·53 ,,	3·52 ,,	3·44 ,,
u	2·13 ,,	2·14 ,,	2·08 ,,

28. At this point it is convenient to examine Professor Robertson's analysis. On pages 172 and 173 of the "Treatise" he defines a quantity L_o as the "Fundamental Length." He calls L_o^2 the "Fundamental Surface," L_o^3 the "Fundamental Volume."

Putting $G=L_o^2$ for convenience in writing $\frac{\partial G}{\partial x}$, $\frac{\partial G}{\partial y}$, etc., we have the defining equation

$$G=\frac{g_i g_c}{4\,h^2}\times\frac{P^2}{g_i A\,.\,g_c B}.$$

The reasoning on pages 172 and 173 of the "Treatise" is difficult to follow; but apparently it amounts to this, that the losses in iron and copper are equal for a maximum efficiency, so that in the notation of this paper $g_i A=g_c B=\frac{1}{2}I$, or each equals half the total losses.

Again it seems to be taken that when the performance is specified, the efficiency is fixed, so that the output is constant, or $P=P_o$ as before, and the total losses are given by $I=I_o$ a constant. Hence

$$P=P_o, \text{ a constant} \quad . \quad . \quad . \quad . \quad . \quad (1)$$
$$g_i A=\tfrac{1}{2}I_o \text{ a constant} \quad . \quad . \quad . \quad . \quad . \quad (11)$$
$$g_c B=\tfrac{1}{2}I_o \text{ a constant} \quad . \quad . \quad . \quad . \quad . \quad (12)$$

It follows that G is a constant "independently of the proportions of the transformer." This constancy of G is really quite arbitrary. Reducing G by means of equations (1), (11), (12), we have

$$G=\frac{x\,y\,z\,u}{4\,(u+y+m\,x)\,(z+x+n\,y)}=G_o\text{, a constant.}$$

Multiplying the volume $G^{3/2}$ by the cost per cubic decimetre of the iron circuit, *i.e.* $\frac{1}{2}k_i$ from § 16, we get a quantity called by Professor Robertson the "fundamental cost," $\frac{1}{2}k_i\,G^{3/2}$.

The ratio of the orthodox cost function $J=k_i A+k_c B$ to the "fundamental cost" is defined as Professor Robertson's cost function

$$\text{Robertson's cost function}=\frac{J}{\frac{1}{2}k_i\,G^{3/2}}.$$

29. To find minimum costs the differential coefficients of this latter function are equated to zero. Before doing so, the homogeneous cubic numerator and denominator are each divided by y^3, and by means of the transformation $X=z/y$, $2\,Y^*=x/y$, $Z=u/y$, we may transform the results of this paper into Professor Robertson's notation, and vice versa.* Retaining the homogeneous form of the equations, as being much more convenient for the formation of partial differential coefficients, we may note that equating

$$\frac{\partial}{\partial x}\left\{\frac{J}{\frac{1}{2}k_i\,G^{3/2}}\right\}=0\text{, etc.}$$

is equivalent to imposing the necessary relations of condition between the variables so that J and $G^{3/2}$ should have stationary values for the same values of the variables. But if $G^{3/2}$ has a stationary value, not zero, so has G, and we get rid of the troublesome factor $\frac{3}{4}k_i G^{1/2}$, which occurs written out in full in each of Professor Robertson's initial equations. These conditions are equivalent to

$$\frac{\partial J}{\partial x}\delta x+\frac{\partial J}{\partial y}\delta y+\frac{\partial J}{\partial z}\delta z+\frac{\partial J}{\partial u}\delta u=0,$$
$$\frac{\partial G}{\partial x}\delta x+\frac{\partial G}{\partial y}\delta y+\frac{\partial G}{\partial z}\delta z+\frac{\partial G}{\partial u}\delta u=0.$$

Eliminating Lagrange's indeterminate multipliers as before, multiplying the rows by x, y, z, u, and remembering that J and G are homogeneous functions of x, y, z, u, of the third and second degrees respectively, and using Euler's theorem relating to homogeneous functions, we get

$$\left\|\begin{matrix} x\frac{\partial J}{\partial x}, & x\frac{\partial G}{\partial x} \\ y\frac{\partial J}{\partial y}, & y\frac{\partial G}{\partial y} \\ z\frac{\partial J}{\partial z}, & z\frac{\partial G}{\partial z} \\ u\frac{\partial J}{\partial u}, & u\frac{\partial G}{\partial u} \\ 3J, & 2G \end{matrix}\right\|=0.$$

30. It is to be noted that G in Professor Robertson's system takes the place of P in the correct system of § 24.

Professor Robertson's equations of condition are identical with those formed by taking rows (1) and (5), (3) and (5), (4) and (5) of the last matrix, and equating the determinants so formed to zero.

The condition obtained by taking rows (2) and (5) is lost in his analysis by dividing the numerator and denominator by y^3; but as it is not an independent condition, the equivalence of the two methods is unaffected. If we take these three independent conditions along with the implied condition, $G=G_o$, we have sufficient equations to solve

* Professor Robertson takes *half* the window width as his standard dimension.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

The first independent relation which we [illegible] down, is an equation of the seventh degree which does not give the same useful root as the correct cubic.

32. It would have been unnecessary to follow in such detail a piece of analysis evidently based on faulty assump- [illegible] obtained are correct. It will be noticed that the general [illegible] to a shell-type transformer, contains as particular cases the [illegible] (6) denote the equations so numbered. It is entirely owing [illegible] which lead from Professor Robertson's incomplete and [illegible] two correct conditions found, namely (5) and (6), out of four required.

[illegible] "Treatise," that taking ratios of variables reduces the number of variables by one, was also made by Messrs. [illegible]

[illegible] unrestricted by the temperature rise, and the flux, flux density, and dimensions are constant) is applied on

[illegible]

[illegible]

[illegible]

[illegible]

[illegible] circuits.

34. If we seek for minimum losses subject to $P = P_0$, [illegible] of a higher order of infinitesimals than the reciprocals of [illegible] the terms containing the lowest power of μ or ν (namely [illegible] are indefinitely small.

35. It is necessary to assume another condition in order to make the problem determinate. Let this condition be the assumption that the cost J has a fixed limit, then

[illegible]

[illegible] Lagrange's indeterminate multipliers, we get multiplying the 1st, 2nd, etc., rows by x, y, etc.

[illegible]

J and P are homogeneous in $x, y, \ldots u, \mu, \nu$, but I is not, so that Euler's theorem of homogeneous functions cannot be used. The first four rows of this matrix are equivalent to the matrix of Section 21 which leads to Equations (5) and (6), for I and J are linear functions of A and B with respect to x, y, z, and u (but not of course with respect to μ and ν). Hence (5) and (6) are still conditions in the most general case.

36. The last two rows taken with any other row at once reduce to

$$\begin{vmatrix} 1 & \mu\frac{\partial I}{\partial \mu} \\ 1 & \nu\frac{\partial I}{\partial \nu} \end{vmatrix} = 0, \qquad \text{or } \mu\frac{\partial I}{\partial \mu} = \nu\frac{\partial I}{\partial \nu} \quad . \quad . \quad (14)$$

Writing these out in full in the notation of this section

$$m\,(1{\cdot}6\,a\,\mu^{1{\cdot}6} + 2\,b\,\mu^2)\,y\,u\,(x + y + n\,y) = m \times 2\,c\,\nu^2\,x\,\text{[illegible]}\,(u + y + m\,x).$$

This may be put in the form

$$\frac{m\,c\,\nu^2\,\text{B}}{m\,(a\,\mu^{1{\cdot}6} + b\,\mu^2)\,\text{A}} = \frac{1{\cdot}6\,a\,\mu^{1{\cdot}6} + 2\,b\,\mu^2}{2\,a\,\mu^{1{\cdot}6} + 2\,b\,\mu^2}.$$

The left-hand expression is seen to be the ratio of copper loss to iron loss. The right-hand expression increases continuously from the value 0·8 for $\mu = 0$ to unity for $\mu = \infty$; hence the ratio of the losses lies between 0·8 and 1. This result has already been given by several writers, but without the above proof that it is consistent with the most general conditions.

37. We have so far five conditions between the six variables, namely $P = P_0$ (1), $J = J_0$ (13), (5), (6), and (14).

To get a sixth we take any pair of the first four rows with either of the last two rows and equate the determinant so formed to zero. Taking the first, second, and sixth rows, this gives after some reduction, obvious after what has already been done,

$$\begin{vmatrix} 1 & x\frac{\partial I}{\partial x} & x\frac{\partial J}{\partial x} \\ 1 & y\frac{\partial I}{\partial y} & y\frac{\partial J}{\partial y} \\ 1 & \nu\frac{\partial I}{\partial \nu} & 0 \end{vmatrix} = 0,$$

whence subtracting the third row from the second and from the first we get at once

$$\frac{x\frac{\partial J}{\partial x}}{y\frac{\partial J}{\partial y}} = \frac{x\frac{\partial I}{\partial x} - \nu\frac{\partial I}{\partial \nu}}{y\frac{\partial I}{\partial y} - \nu\frac{\partial I}{\partial \nu}}$$

writing out these expressions in full

$$\frac{k_2\,y\,u\,x + k\,x\,\text{[illegible]}\,(u + y + 2\,m\,x)}{k_2\,y\,u\,(x + y + 2\,n\,y) + k\,\text{[illegible]}}$$

$$= \frac{m_2\,(a\,\mu^{1{\cdot}6} + b\,\mu^2)\,y\,u\,x - m\,c\,\nu^2\,x\,(u + y)}{m_2\,(a\,\mu^{1{\cdot}6} + b\,\mu^2)\,y\,u\,(x + y + 2\,n\,y) - m\,c\,\nu^2\,x\,(2\,u + y + 2\,m\,x)} \quad (15)$$

The reduction of the system of the six equations between x, y, z, u, μ, ν, viz. (1), (5), (6), (13), (14), (15) will obviously involve lengthy arithmetic.

38. If we seek minimum costs for a given output without regard to losses, we get again, as in § 34, an indeterminate problem. In this case the dimensions are indefinitely small, of the order ϵ say, and the densities indefinitely large and of the order $1 \div \epsilon^2$, while the losses, containing terms with the factor $(1 \div \epsilon^2)^2 \times \epsilon^3$, are indefinitely large.

We may make the problem determinate by assuming that the losses have a definite finite value

$$I = I_0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (16)$$

We then get the same system as in § 35 but with Equation (16) substituted for Equation (13).

The present author has not carried the problem further.

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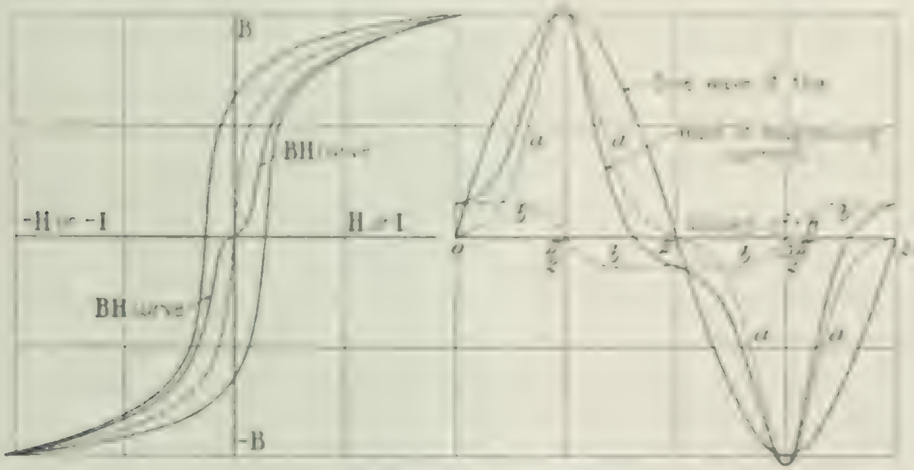
[illegible]

MATHEMATICAL RELATIONSHIP BETWEEN FLUX AND MAGNETIZING-CURRENT WAVES AT HIGH FLUX DENSITIES.

By A. L. Tackley, B.Sc.

[illegible]

[illegible]



[illegible]

As an introduction to the mathematical treatment of this subject, it is desirable to consider the relation between flux and magnetizing-current waves at normal flux densities.

In Fig. 1 the magnetizing-current wave required in [illegible] by the dotted line which bisects its horizontal width—this [illegible]

[illegible]

other line is shown in Fig. 1 within each half of the hysteresis loop, namely, the B–H curve as obtained by the method of reversals with a ballistic galvanometer.

Now if the magnetization reaches high flux densities, the width of the loop becomes so small compared with the maximum value of the magnetizing current that its influence on the shape of the magnetizing-current wave becomes negligible. The latter may therefore be derived directly from the line bisecting the loop, and its analysis will yield only sine terms, giving

$$a_1 \sin\theta - a_3 \sin 3\theta + a_5 \sin 5\theta - \text{etc.} \quad . \quad . \quad . \quad (2)$$

Also since the width of the loop is negligible this bisecting line may be replaced by the corresponding B–H curves, since both are contained within the loop.

Proceeding to the B–H curve for the "Stalloy" iron used in Mr. Nicholson's experiments, Fig. 2 shows the

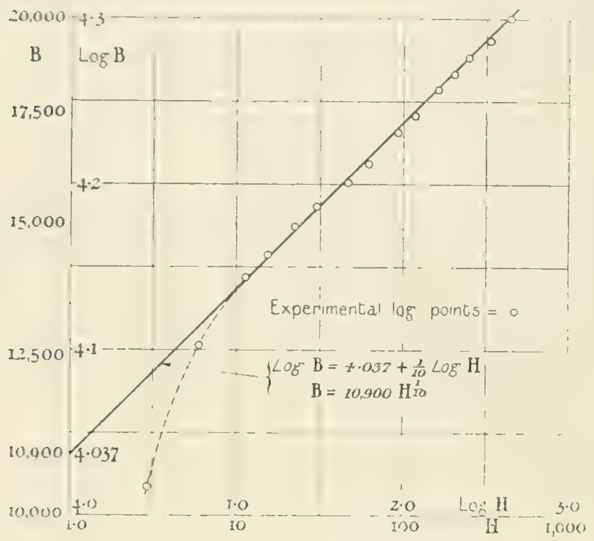


FIG. 2.—Analysis of B–H Curve. Log B Plotted against log H.

corresponding log B, log H curve. The equation to the straight-line portion of this graph is given by

$$\log B = 4{\cdot}037 + 0{\cdot}1 \log H$$

so that $$B = 10900\, H^{\frac{1}{10}} \quad \text{or} \quad H = \left(\frac{B}{10900}\right)^{10} \quad . \quad . \quad . \quad (3)$$

The accuracy of these equations when applied to the B–H curve has been checked in Fig. 3, from which it will be seen that the calculated curve would practically coincide with one drawn from experimental data at high flux densities. For low values of B the curve, although not accurately representing the B–H curve, would lie within the hysteresis loop for the high flux-density conditions considered above. For the present purpose Equation (3) will therefore be used instead of the B–H curve. It is written more generally in Equation (4).

$$B = K_1\, I^{\frac{1}{10}}, \quad \text{or} \quad I = K_2\, B^{10} \quad . \quad . \quad . \quad . \quad (4)$$

Consider now an electric circuit consisting of a single-phase alternator maintaining a sine wave of voltage of normal frequency f when connected to the magnetizing winding of a laminated-iron magnetic circuit. Assume the total resistance of the circuit (including the resistance of the alternator) is negligible and that, the iron being

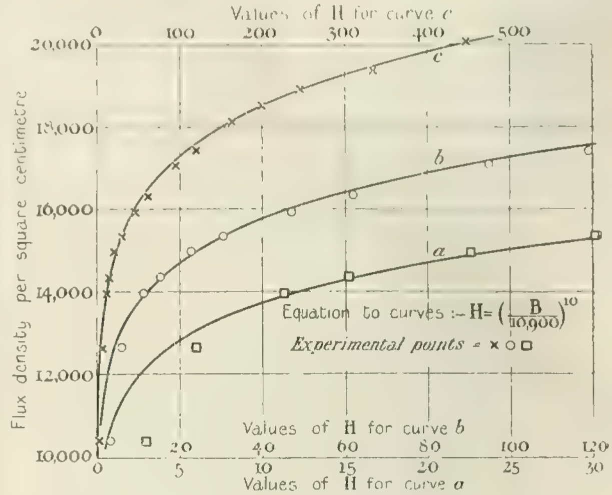


FIG. 3.—Experimental and Calculated B–H Curves.

worked to high flux densities, it is possible to neglect the influence of hysteresis on the shape of the magnetizing-current wave. Then if the influence of eddy currents may also be neglected there are two limiting cases which may be considered mathematically, namely, the effect of producing—(1) a sine wave of magnetizing current in the electric circuit, or (2) a sine wave of magnetic flux in the iron circuit.

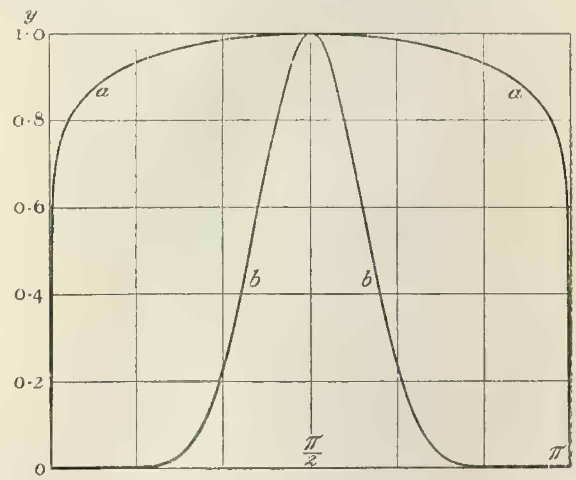


FIG. 4.

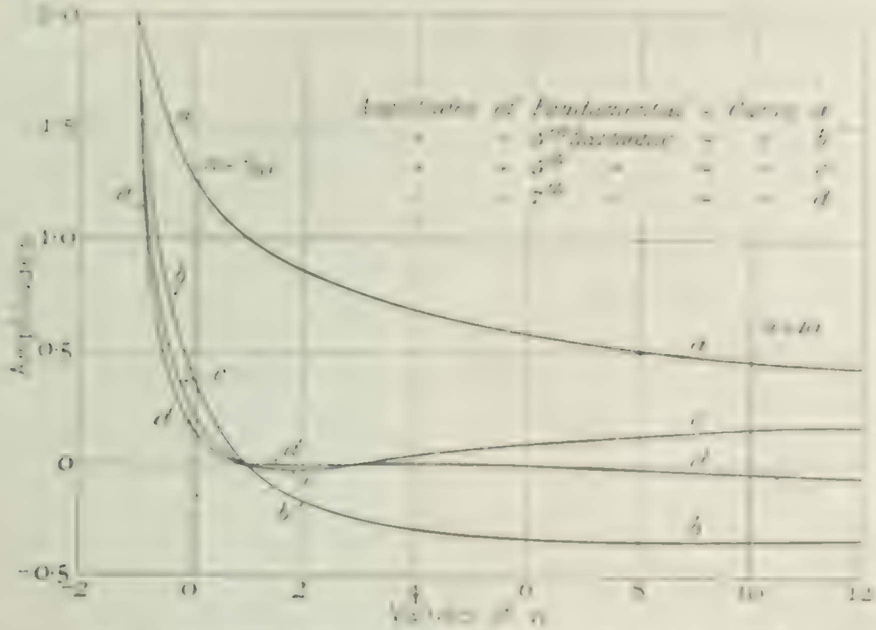
(a) $y = \sin^{\frac{1}{10}}\theta$; (b) $y = \sin^{10}\theta$.

Case 1.—Let $i = I_M \sin\theta$ be the magnetizing current, where $\theta = \omega t$, $t =$ time and $\omega = 2\pi f$. Then by Equation (4) the curve of flux density B produced by this current is given by

$B = + K_1\, I_M^{\frac{1}{10}} \sin^{\frac{1}{10}}\theta$ for values of θ between 0 and π, and

$B = - K_1\, I_M^{\frac{1}{10}} \sin^{\frac{1}{10}}\theta$ for values of θ between π and 2π. (5)

[illegible]



[illegible]

obtained from Equation (7), namely

[illegible]

on the number of turns of the magnetizing winding, the [illegible]

[illegible] to hysteresis and eddy currents. Since hysteresis is practically independent of the rate of change of flux with time, the flux wave [Equation (6)] gives the same hysteresis loop [illegible] magnitude depends on the time rate of change of the flux, [illegible] and phase, and on the permeability and [illegible] maximum value of which, Φ_M, will re[illegible] changed. It is interesting to notice that [illegible]

resultant flux wave must also contain the term $\Phi_F \sin\theta$ unchanged, since the magnitude and phase of the latter are determined by the applied voltage wave. The eddy currents can therefore only modify the harmonic terms of Equation (7), and the resultant flux wave will be of the form

$$\Phi = \Phi_F \sin\theta + \Phi_3 \sin 3(\theta - \alpha_3) + \Phi_5 \sin 5(\theta - \alpha_5) + \text{etc.} \quad . \quad (9)$$

The current wave will now include a fundamental term tending to neutralize the magnetic effect of the fundamental eddy currents, and also a fundamental cosine term in phase with the applied voltage to supply the total eddy-current ohmic loss. The magnitude of this loss depends on the square of the form factor of the resultant induced voltage wave.

The case considered above readily leads to Case 2, that of a sine wave of flux in the iron. Thus, suppose no resonance device to be inserted in the electrical circuit which, in contrast to the eddy-current paths in the iron, now possesses by assumption only inductance, then the flux will produce harmonic currents in the winding, lagging $\pi/2$ behind the harmonic voltages producing them. The direction and phase of these currents causes them to oppose and reduce the harmonic fluxes, which will result in the flux wave tending towards a sine wave. This action is, however, limited by the inductance of the complete circuit to the harmonic currents, but if these currents can be assisted to reach their full values the flux wave will become a sine wave. This case will be now considered.

Case 2.—Let $\Phi = \Phi_M \sin\theta$ be the flux wave giving $B = B_M \sin\theta$. Then by Equation (4) and as above, consider only a half period, the curve of current to produce this flux is given by

$$i = K_2 B_M^{10} \sin^{10}\theta \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

The shape of the current wave (10) has been plotted in Fig. 4, curve *b*. Also by analysis (see Fig. 5, $n = 10$) Equation (10) may be written

$$\left.\begin{aligned} i &= I_M (0{\cdot}47 \sin\theta - 0{\cdot}32 \sin 3\theta \\ &\qquad + 0{\cdot}15 \sin 5\theta - 0{\cdot}04 \sin 7\theta + \text{etc.}) \\ &= I_F (\sin\theta - 0{\cdot}69 \sin 3\theta \\ &\qquad + 0{\cdot}32 \sin 5\theta - 0{\cdot}085 \sin 7\theta + \text{etc.}) \end{aligned}\right\} \quad (11)$$

where $I_M = K_2 B_M^{10}$ and I_F (the amplitude of the fundamental wave) $= 0{\cdot}47\, I_M$.

With regard to the accuracy of the assumptions made for this case, hysteresis has already been considered. Regarding the eddy currents, these are of the fundamental frequency, and returning to waves of normal flux densities their effect may be approximately represented by increasing amplitudes a_1, b_1 of (1) to $(a_1 + \alpha)$ and $(b_1 + \beta)$, where α corresponds to screening action and β is due to this action and ohmic loss. Assuming the screening action to be negligible, α, which modifies the slope of the resulting hysteresis and eddy-current loop, may be neglected, while $(b_1 + \beta)$ is the approximate half width of this loop. Now $(b_1 + \beta)$ can be compared with I_M from the fact that all terms of (1) other than $(b_1 + \beta)\cos\theta$ are wattless. Taking normal values for the total hysteresis and eddy-current iron loss at 50 periods per second and with 0·5 mm. thickness of the "Stalloy" laminations, we have

$(b_1 + \beta)$ approximately 0·5 per cent of I_M, for $B_M = 20{,}000$.

The width of the hysteresis loop when the eddy-current loss is included therefore still remains negligible at high flux densities, and the shape of the magnetizing-current wave will again reduce to (2), namely

$$a_1 \sin\theta - a_3 \sin 3\theta + a_5 \sin 5\theta - a_7 \sin 7\theta + \text{etc.}$$

This limiting case was approached by Mr. Nicholson in experiments in which the third harmonic current was given such values that the corresponding harmonic flux was completely removed from the magnetic circuit. The result that he obtained by analysis of oscillograms of the magnetizing-current wave is now given for comparison, namely

$$i = I_F (\sin\theta - 0{\cdot}63 \sin 3\theta + 0{\cdot}25 \sin 5\theta - 0{\cdot}10 \sin 7\theta) \quad . \quad (12)$$

The above equation was the approximately constant result obtained for values of B_M in the iron 17,500–20,000 lines per square centimetre, neglecting slight displacements of the harmonics relative to the fundamental term.

In comparing (11) and (12) it must be remembered that the flux curve in the experiments was not quite a sine wave owing to the impedance of the circuit to the fifth, seventh, etc., harmonics. The displacements of the harmonics referred to above are partly due to this cause, which will also result in the relative amplitudes of the harmonics of (12) being less than those of (11). This is the case except for the seventh harmonic, the greater magnitude of which in (12) may possibly be due to the presence of a seventh harmonic in the voltage generated by the alternator used in the experiment.

From the foregoing it will be seen that making other assumptions regarding the conditions of the electric circuit will enable other curves of current and flux to be deduced. One case intermediate between those already considered is that obtained by Mr. Nicholson with the star- and mesh-connected windings on his three iron testers by leaving the mesh winding on open circuit. For this case no third, or multiple of the third, harmonic current can be induced in the star-connected magnetizing windings by the corresponding flux harmonics. Assuming all other harmonics of current to reach their maximum values, the flux wave will contain only the third, and multiples of the third harmonic. Neglecting higher multiples than the ninth harmonic, the shape of the flux wave will be given by

$$\Phi = \Phi_M (\sin\theta + d_1 \sin 3\theta + d_2 \sin 9\theta) \quad . \quad . \quad . \quad (13)$$

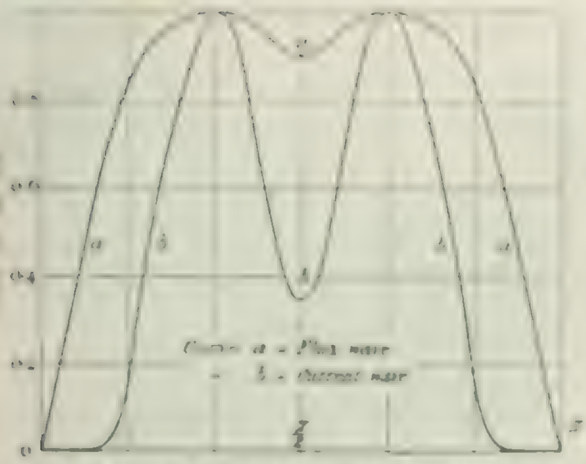
Then by (4) the current wave for a half period required to produce (13) is given by

$$i = K_2 B_M^{10} (\sin\theta + d_1 \sin 3\theta + d_2 \sin 9\theta)^{10} \quad . \quad (14)$$

d_1 and d_2 can now be obtained from (14) using mathematically the condition stated above, that the current wave when analysed cannot contain the third or multiples of the third harmonic. This gives (approximately) $d_1 = 0{\cdot}20$ and $d_2 = -0{\cdot}02$. The induced voltage can now be obtained from (13) after inserting the values of d_1, d_2, namely

$$\left.\begin{aligned} e_i &= -E_{iF} (\cos\theta + 3 \times 0{\cdot}20 \cos 3\theta - 9 \times 0{\cdot}02 \cos 9\theta) \\ &= -E_{iF} (\cos\theta + 0{\cdot}60 \cos 3\theta - 0{\cdot}18 \cos 9\theta) \end{aligned}\right\} (15)$$

[illegible]


0·8
0·6
0·4
0·2
0
a
b
Curve a = Flux wave
" b = Current wave

[illegible]

DISTRIBUTION AND RISE OF TEMPERATURE IN FIELD COILS.

By Professor MAGNUS MACLEAN, D.Sc., Member, D. J. MACKELLAR, B.Sc., Associate Member, and R. S. BEGG, Graduate.

(*Paper first received* 18 *August, and in final form* 20 *November,* 1914; *read before the* SCOTTISH LOCAL SECTION 9 *February,* 1915.)

A considerable amount of experimental work on this subject is already available in the *Journal,* notably the results given by Mr. E. Brown,* Mr. E. H. Rayner,† and Mr. G. A. Lister,‡ and the discussions on these papers.

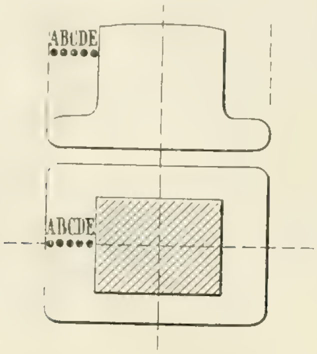


FIG. 1.

In ordering recently a continuous-current motor for the Royal Technical College, Glasgow, the makers were asked to insert in one of the field coils five thermo-couples as shown in Fig. 1. The object was to determine the temperature rise at various points in a field coil of a 120 kw.

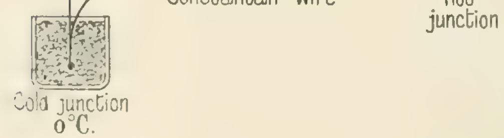


FIG. 2.

variable-speed continuous-current motor, under various conditions of load, at various speeds, and with various field currents; and to deduce a heating coefficient for use in designing the field coils for a machine of this type. The motor is connected to an alternator, both machines being of the open type and mounted on a bedplate with four bearings.

The motor is compound wound for a pressure of 500 volts with a speed variation from 360 r.p.m. to 900 r.p.m. by shunt regulation only. It is a 6-pole machine with a compensating winding and also a commutating-pole winding.

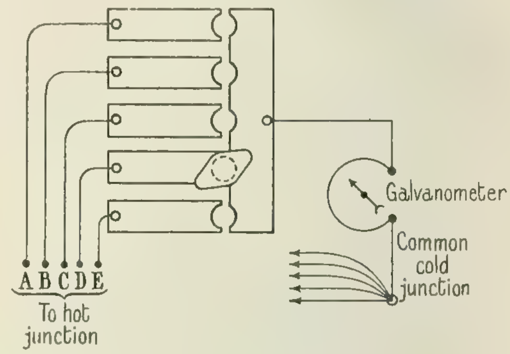


FIG. 3.

The armature winding is copper strip in two layers of four conductors in each slot, each slot being closed by a wooden wedge. The alternator gives an output of 125 k.v.a. at $\cos \phi = 0{\cdot}8$ and 750 r.p.m., the frequency being 50; and

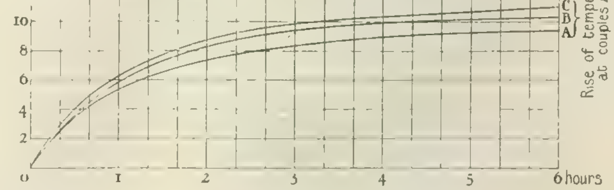


FIG. 4.

Speed 750 r.p.m.
Motor armature current 8 amperes
Field current 1·2 amperes.

the pressure can be varied from 144 to 500 volts according as the coils are joined in delta or star and connected in parallel or series.

The thermo-couples, consisting of copper-constantan, were placed in one of the shunt field-coils, as shown in

* *Journal I.E.E.,* vol. 30, p. 1159, 1901.
† *Ibid.,* vol. 34, p. 613, 1905.
‡ *Ibid.,* vol. 38, p. 399, 1908.

[illegible]

[illegible]

Fig. 5.

[illegible]

[illegible] the plug each thermo-couple could be connected to the [illegible] with a vertical coil suspended by phosphor-bronze strips. [illegible]

[illegible]

[illegible] in the ar[illegible] the next [illegible] and 570 r.p.m.

[illegible]

Table [illegible]

No. of Test	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	8·0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	50·0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	1·65	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10·5	[illegible]	[illegible]
9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

The readings of the temperatures of the thermo-junctions were taken every 5, 10, or 20 minutes, depending on the rate of rise of temperature. For each set of readings five sheets of curves were drawn, one for each thermo-junction, showing on a time base—

(*a*) room temperature,
(*b*) actual temperature of thermo-junction,
(*c*) rise of „ „

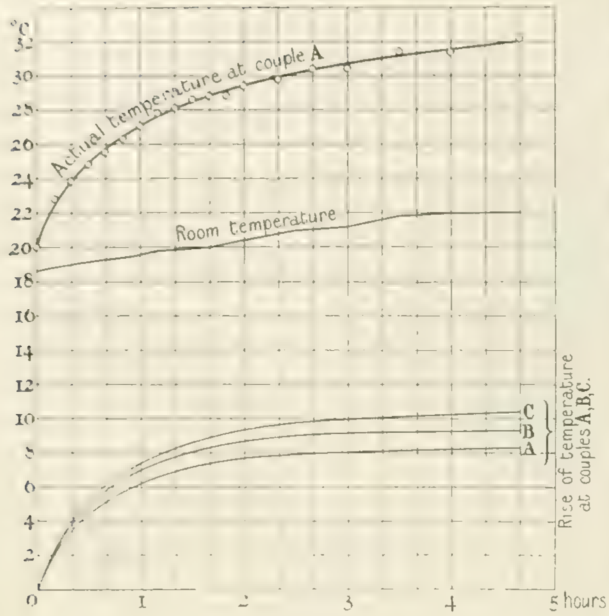


FIG. 7.

Speed 750 r.p.m.
Motor armature current 50 amperes.
Field current 1·2 amperes.

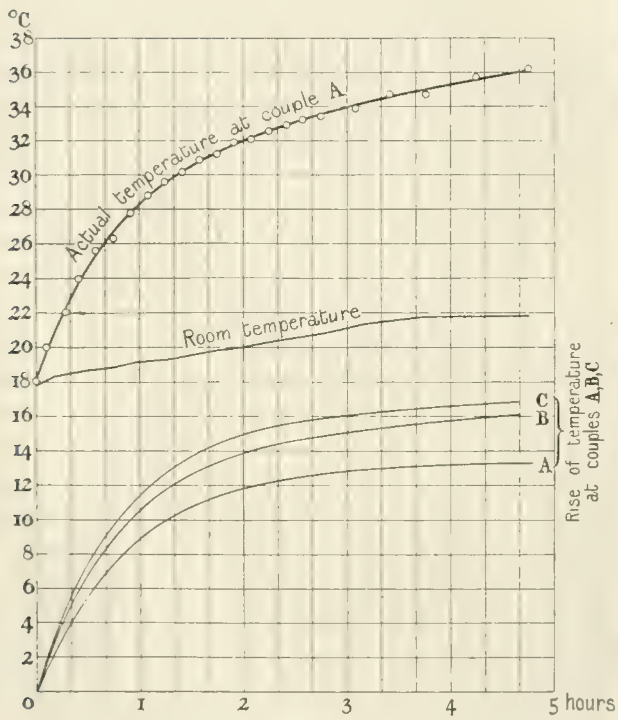


FIG. 8.

Speed 570 r.p.m.
Motor armature current 50 amperes.
Field current 1·65 amperes.

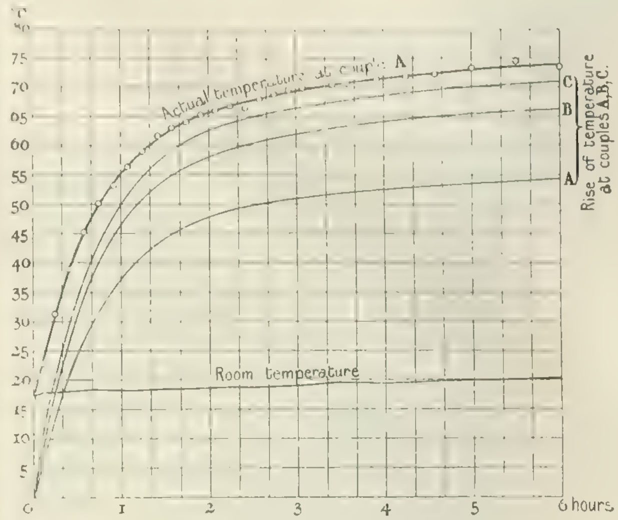


FIG. 9.

Speed 380 r.p.m.
Motor armature current 50 amperes.
Field current 3·5 amperes.

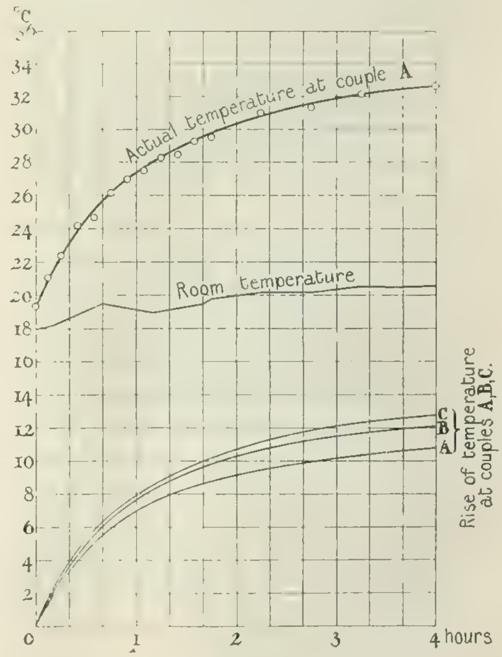


FIG. 10.

Speed 745 r.p.m.
Motor armature current 100 amperes.
Field current 1·2 amperes.

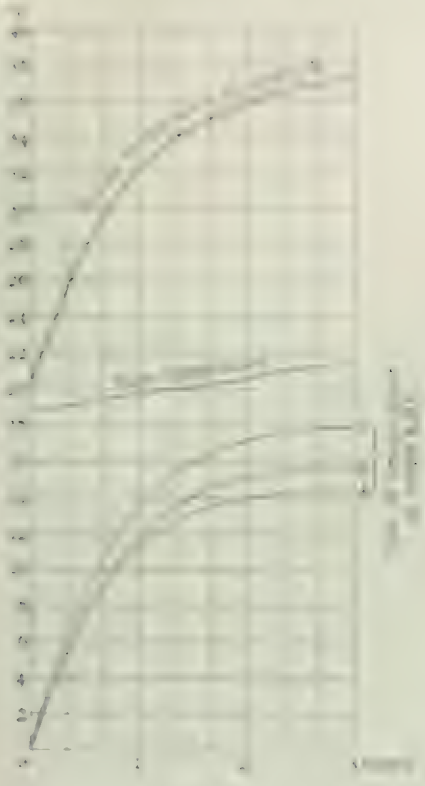


Fig. 11.

Speed [illegible] r.p.m.
Motor armature current [illegible] amperes.
Field current [illegible] amperes.

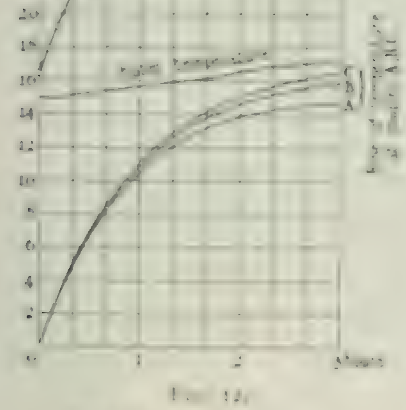


Fig. 12.

Speed [illegible] r.p.m.
Motor armature current [illegible] amperes.
Field current [illegible] amperes.

[illegible] with these curves on each other. For the purposes of this paper they have been reduced to the [illegible].

Fig. 13.

Speed [illegible] r.p.m.
Motor armature current [illegible] amperes.
Field current [illegible] amperes.

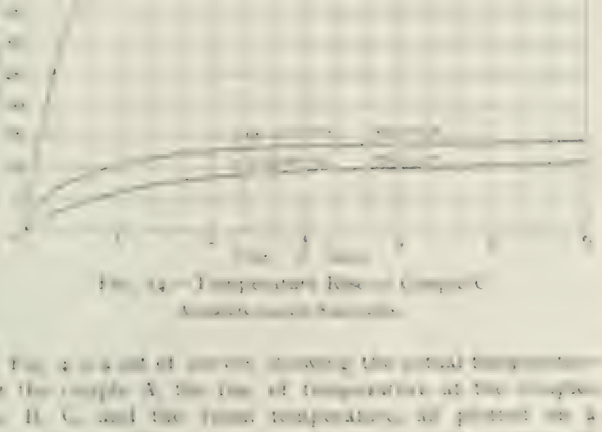


Fig. 14.—Temperature Rise of Compact [illegible]

Fig. [illegible] is a set of curves showing the actual temperature at the couple A, the rise of temperature at the couples A, B, C, and the frame temperature, all plotted on a time base. These curves are for a field current of [illegible] amperes and an armature current of [illegible] amperes. The rise of temperature of B is as much that of A and

that of D so nearly that of B, that they are omitted from the figures. This can be seen from the distribution curves given in Figs. 18 to 21.

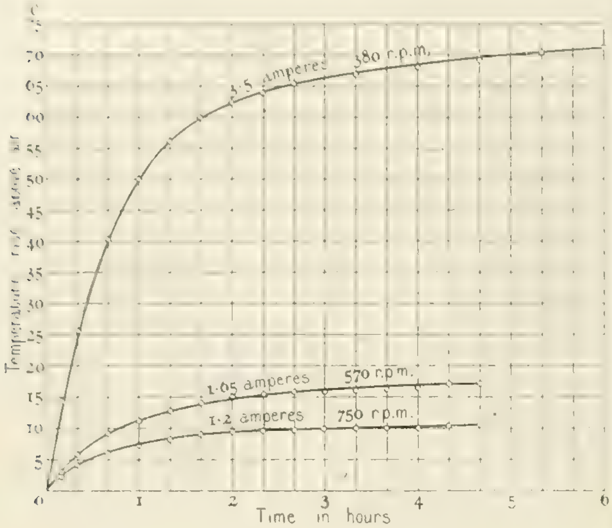


FIG. 15.—Temperature Rise of Couple C.
Armature current 50 amperes.

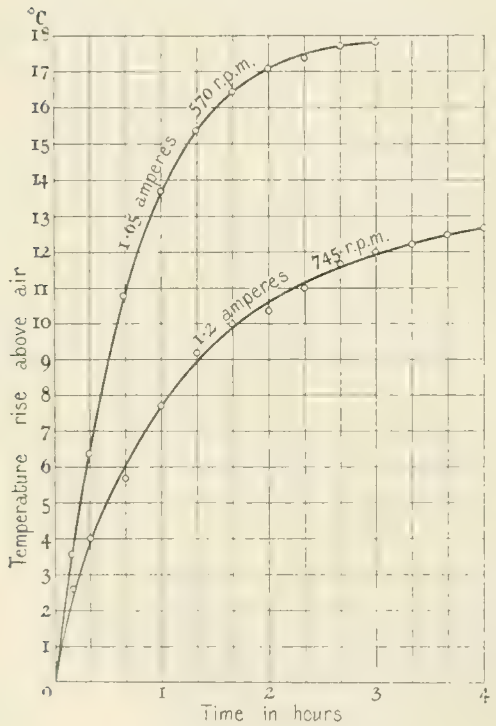


FIG. 16.—Temperature Rise of Couple C.
Armature current 100 amperes.

	Field Current	Armature Current
Fig. 5 gives a similar set of curves	1·65 amp.	8 amp.
„ 6 „ „	3·5 „	8 „
„ 7 „ „	1·2 „	50 „
„ 8 „ „	1·65 „	50 „
„ 9 „ „	3·5 „	50 „
„ 10 „ „	1·2 „	100 „
„ 11 „ „	1·65 „	100 „
„ 12 „ „	1·2 „	150 „
„ 13 „ „	1·65 „	150 „

In order to compare these rises of temperature readily for the various speeds, in Fig. 14 curves are given showing the rise of temperature at the hottest junction, namely the couple C, for an armature current of 8 amperes and for three different field currents, viz. 1·2, 1·65, and 3·5 amperes, the curves being plotted on a time base.

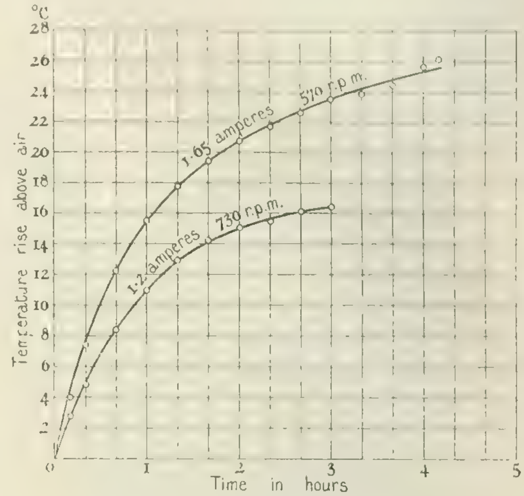


FIG. 17.—Temperature Rise of Couple C.
Armature current 150 amperes.

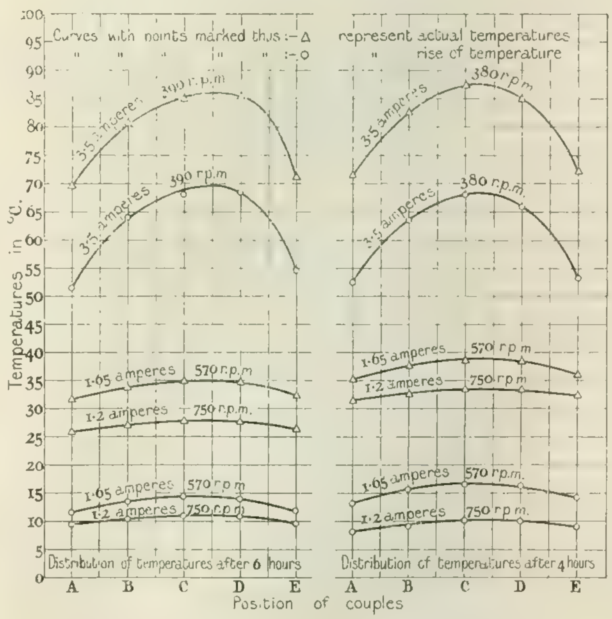


FIG. 18.
Armature current 8 amperes.

FIG. 19.
Armature current 50 amperes.

Fig. 15 gives similar curves for an armature current of 50 amperes.

Fig. 16 gives similar curves for an armature current of 100 amperes.

Fig. 17 gives similar curves for an armature current of 150 amperes.

Four figures are given to show the variation of the temperature rise with the distance through the thickness

TABLE [illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3·5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

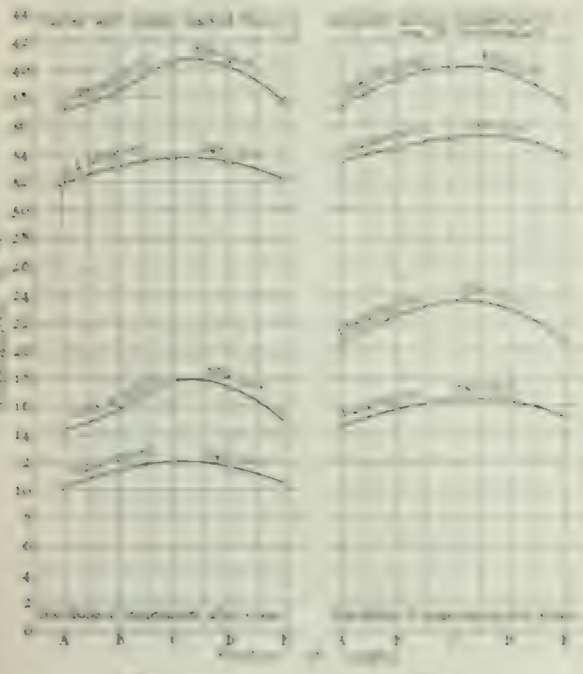


FIG. 20. FIG. 21.

[illegible]

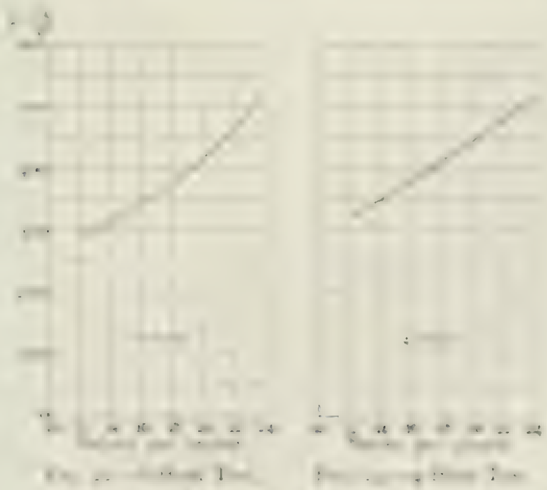
Fig. 18 gives the distribution for three different field currents at the end of six hours when the armature current is 8 amperes.

Fig. 19 gives a similar set of curves at the end of four hours when the current in the armature is [illegible] amperes.

Fig. 20 gives a similar set of curves at the end of [illegible] hours when the current in the armature is 100 amperes.

Fig. 21 gives a similar set of curves at the end of three hours when the current in the armature is 150 amperes.

[illegible] to note that the ratio of the final rise of temperature to the



[illegible]

[illegible] shown in Table 2. It should be noted that a speed [illegible] armature of 23·50 metres per second. On the other hand [illegible]

[illegible]

[illegible]

If this equation is applied to the results in the above table at a load of 8 amperes in the armature and is solved for the three speeds, the three simultaneous equations give three results, the mean of which gives $a = 198{\cdot}6$ and $b = -0{\cdot}0263$. Substituting these values of a and b, the results set out in Table 3 herewith are obtained.

The figures given in Table 3 have also been plotted in Fig. 22.

The results obtained by dealing similarly with the rises of temperature in four hours and with a current of 50 amperes in the armature are 512, 414, and 325 respectively, and are given in Fig. 23, the mean values of a and b being 232·8 and −0·023 respectively.

TABLE 3.

Peripheral Speed of Armature in Metres per Second	$\frac{198{\cdot}6}{1 - 0{\cdot}0263\,v}$
23·56	524
17·9	376
12·25	293

DISCUSSION.

Professor Baily. Professor F. G. BAILY: This paper is particularly interesting to me, because curiously enough I have in my own laboratory a similar arrangement on a smaller scale. I have five coils and five thermo-junctions with a 10 h.p. motor instead of one rated at 120 kilowatts, but I have not carried out so many tests as the author has. I do not understand the result which the author states he has obtained on his machine, namely, that the more he cools it the hotter it gets. I do not wish to criticize his experiments, but I was surprised to notice that b has a negative sign throughout. I shall look forward with great interest to the further paper that the author has promised; and meantime I shall carry out further tests on several machines and compare notes with the author in due course. In connection with variable-speed motors, the point to which the author draws attention is very important.

Mr. Nicholson. Mr. J. S. NICHOLSON: Like the previous speaker I was impressed by the results shown in Table 2 and plotted in Figs. 22 and 23, and I felt that they required further explanation. On page 402 of Lister's paper * in volume 38 of the *Journal* there will be found the statement that "If all these conditions remain constant it will still be found that the coefficient varies with the final temperature attained by the coil." Lister found that the heating coefficient C_h (represented by $k = t\,A/W$ in Figs. 22 and 23 of Professor Maclean's paper) diminished as the temperature increased; that is, the watts dissipated per unit of coil surface increased at a greater rate than the mean final temperature of the coil. Professor Maclean's figures in the last column of Table 2 agree with what Lister found. So far as I can see, the armature speed has an inappreciable influence on the heating coefficient, or rise in temperature ÷ watts; or else its influence is masked by some other variable. The compensating windings in the pole-shoes will to some extent prevent ventilation of the field coils by the armature, and the difference in the speed will make little difference in the cooling. Experiments on heating are usually very difficult to carry out successfully; there are so many variables that one must be very careful in drawing conclusions from the results of a limited number of experiments.

Professor Cormack. Professor J. D. CORMACK: I should like to know whether the authors noted the barometric pressure, and whether its variation had any appreciable effect.

Mr. McWhirter. Mr. W. McWHIRTER: I should like to ask the author whether there was any reason for keeping the thermo-couples outside instead of inside. Is it not possible that the rise in temperature when the machine was running at the higher speed was due to hysteresis?

* G. A. LISTER. The heating coefficient of magnet coils. *Journal I.E.E.*, vol. 38, p. 399, 1907.

Mr. Symons. Mr. H. SYMONS: The number of variables that one has to contend with in an investigation of this nature necessitates the exercise of considerable patience, and I think the authors are to be congratulated upon taking up this question of the temperature rise in field coils, the somewhat tedious nature of which will be appreciated by those who have carried out work of a like nature. It is an important subject, on which a good deal remains to be done, and one which is of particular interest to me. If the authors have the opportunity, I would suggest that they should make a series of tests on the same coils and obtain the ratio between the temperature rise at the hottest part and the mean temperature rise as measured by the variation in resistance. Very few tests are available in connection with this important ratio. The value of the investigations would also be very considerably increased by a series of tests showing the results obtained with a number of coils wound and insulated in different ways. The manner in which coils are wound and insulated affects very materially the temperature rise and temperature distribution, and, consequently, the ratio between the hottest-point temperature and the mean temperature rise as measured by the variation in resistance. The variables that have to be borne in mind for an investigation such as the authors have commenced depend to a considerable extent on the type of machine, since the fanning action of the armature is an all-important factor in the ultimate temperature rise, but the reason for the result obtained by the authors, viz. an increase in the ratio of the final temperature rise to the number of watts with increasing speed, is not altogether apparent. The manner in which the fanning air strikes the surface of the coils and the nature of this surface are two important factors in determining the temperature rise, and I suggest that, with the machine on which the authors have carried out their experiments, the increased fanning action of the armature due to increased speed is not for some reason utilized to the same extent for the cooling of the coils as is usual in the ordinary types of machines. There may be many reasons for this, and in this connection it is to be noted that the machine tested by the authors has commutating poles; if feasible, a series of tests with the commutating poles removed would be of interest and value. In conclusion, I hope that the authors will not only continue their work, but also extend it to other types of machines.

Professor M. Maclean (*in reply*): Professor Barr, Mr. Nicholson, and Mr. Sommer have all remarked on the decrease of the heating coefficient with an increase of the armature speed. [illegible]

[illegible] The discussion [illegible]

ELECTRIC STEEL-MAKING FURNACES.

By F. D. Robertson.

[illegible]

The melting and refining of steel on a commercial scale by means of the heat produced by an electric current has only been possible for a little over 20 years. In this short time, however, considerable progress has been made and a new branch of the iron and steel industry has been successfully developed and established.

The small electric furnaces for laboratory use designed by Siemens over 30 years ago attained considerable perfection, but what prevented their development into sizes applicable to the steel and other industries was that electrical energy was far too expensive to produce. In later years the generation of electrical power by means of rotary machinery at a low cost brought thermo-electric processes into the commercial field.

In places where water power can be developed, electrical energy can be produced wonderfully cheaply, but in this country we have to rely almost entirely on obtaining electrical power from steam, gas, or oil.

The first electric furnaces to work on a commercial scale were all constructed about 1899, and all took their power from water-driven plants. These were the Stassano furnaces in Italy, the Héroult in Savoy, and the Kjellin in Sweden, and it is interesting to note that from these three types have developed the three main classes of electric steel furnaces now in use.

Of course in all electric furnaces the necessary heat is furnished by resistance to the electric current, and the type of furnace depends upon the form which this resistance takes. Owing to the very small electrical resistance of a large mass of iron, it is impracticable to melt iron or steel in bulk merely by passing an electric current through it, as the very low voltage and very large current which would be required would be far too costly to generate and transmit, and, further, the small cross-section which the metal bath would have would involve such high radiation losses that the efficiency of the furnace would be much too low.

Continuous current is not used for steel furnaces, as the cost of special generators to give furnace voltages is high and, moreover, electrolytic actions would be set up in the slag.

Alternating current has many advantages, the chief being the ease with which its pressure can be transformed. For some furnaces, owing to considerations of power factor the frequency has to be specially low, but this is a drawback and most furnaces now work on the usual frequencies. Furnaces using single-phase current are gradually being superseded by those using 2-phase or 3-phase current, as these latter can take their power through static transformers from the usual 3-phase supply mains, or through a more costly and less efficient motor-generator set. Lower frequencies mean rather more expensive transformers, but the inductive losses in the low-tension leads are not so high.

Broadly speaking there are two main classes of electric steel furnaces—induction furnaces and arc furnaces.

In the simple and earlier types of induction furnace the metal bath is in the shape of a ring which is really the short-circuited secondary winding of a transformer contained in the body of the furnace itself. An example of this class is the Kjellin furnace. Single-phase current is supplied to the transformer and an induced secondary current is developed in the iron ring forming the metal bath, of such intensity that the resistance offered by the length and small cross-section of the metal is so great as to generate sufficient heat to melt and maintain the metal in a fluid condition. A section of the Kjellin furnace is shown in Fig. 1.

A is the iron core of the transformer. The primary coil, marked B, is supplied with single-phase current of a convenient pressure. The metal bath, C, is concentric with the primary coil and forms a short-circuited secondary winding of one turn. The ring is of course surrounded by suitable refractory material, and [illegible]

it rests has movable covers for the working and inspection of the charge. The furnace shown in the diagram is fixed, the metal being tapped off through a convenient tap-hole. Later types of the Kjellin furnace, however, are made to tilt upon rockers and so discharge into the receiving ladle. The current in the secondary circuit is very large, being in the case of a furnace of 1-ton capacity about 30,000 amperes at a pressure of 7 volts.

The disadvantage of this type of furnace lies in the fact that some of the molten metal must be left in the furnace at the conclusion of every "heat" in order that a complete circuit may be maintained to start the furnace again.

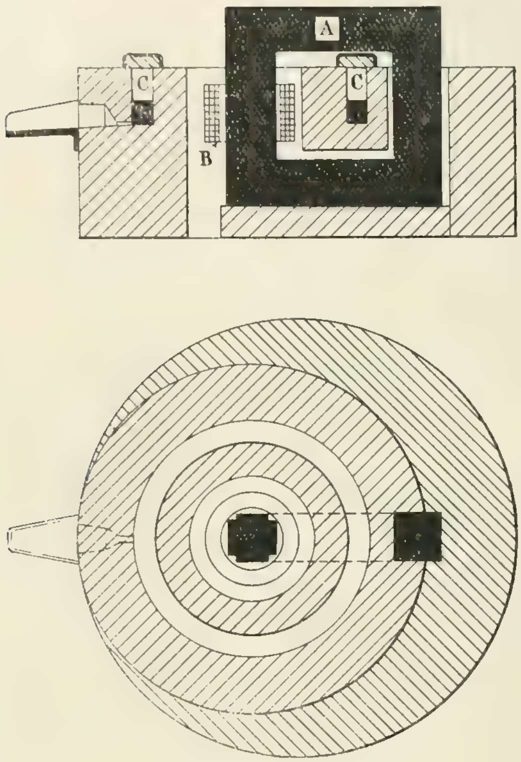


Fig. 1.—Kjellin Furnace.

Cold materials to form the charge are added to this residual metal and a covering of slag is made to protect the charge from atmospheric oxidization. Owing to the difficulty of keeping a suitable refining slag in a fluid condition, and also of removing it after it has taken up impurities from the steel, it is found in practice that very little refining can be done in the simple induction furnace. This means that in order to manufacture first-quality steels raw materials have to be used which contain very small percentages of the injurious elements sulphur and phosphorus—in other words, the simple induction furnace approximates to an electrical melting apparatus which is not, in general, suitable for refining common and impure materials for the production of a high-grade steel.

It is essential for easy refining to have a hearth large enough to allow refining slags to be introduced and withdrawn ; these considerations led to the introduction of the Röchling-Rodenhauser furnace, the principle of which is illustrated in Fig. 2. It will be seen that both legs of the transformer core are provided with primary windings surrounded by induction channels which are joined in the centre to form a working hearth of ample dimensions. This middle part which is of considerably greater cross-section necessitates auxiliary heating, and this is accomplished by means of a secondary winding connected to pole plates which are embedded in the sides of the hearth.

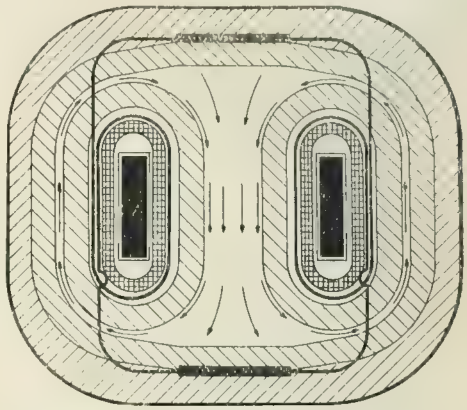


Fig. 2.—Röchling-Rodenhauser Furnace.

The Röchling-Rodenhauser furnace as now constructed is tilted electrically, and the electrical connections are so arranged that the heating may be continued when the furnace is in a tilted position, thus facilitating the removal of the slag. The secondary winding is placed next to, and is separated from, the primary winding by an air space

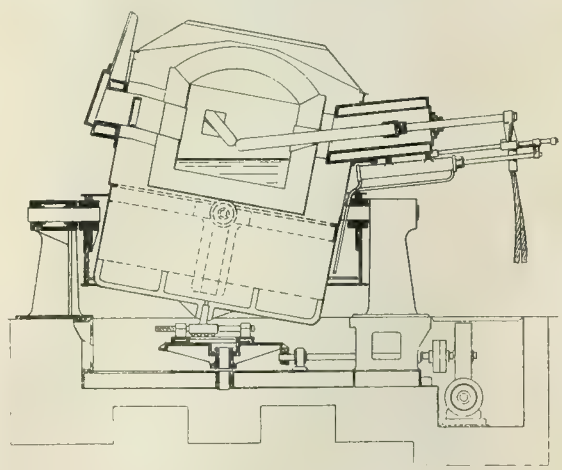


Fig. 3.—Stassano Furnace.

which serves as a cooling chamber. This secondary winding is composed of heavy copper strips and carries very large currents at low voltages. From these strips, copper connections lead to pole plates of mild steel embedded in the sides of the hearth wall and separated from the molten metal by this part of the basic lining. The transformer windings are air-cooled, as otherwise they would become too hot, partly from their own action and partly from the heat radiated to them from the surrounding furnace casing.

[illegible]

[illegible]

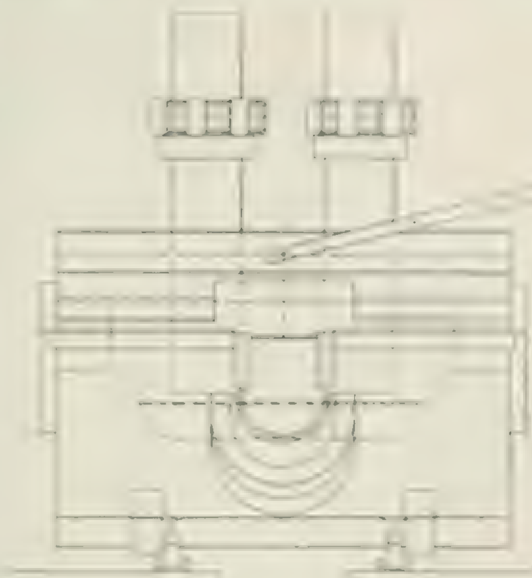
[illegible]

in the latter the arc is struck between the ends of one [illegible] and the charge itself, the current either passing along the surface of the charge to the other electrodes, or else passing through the body of the charge itself to an electrode in the bottom of the [illegible]

The main furnace of the former class is the Stassano [illegible] [illegible] used in the experimental reduction of iron ores. Later, however, it came to be employed entirely for steel melting, and in small sizes is in use at the present day. Its general arrangement is shown in Fig. 3. There are three electrodes inclined slightly to the horizontal forming angles of 120° with one other. Three-phase current is employed usually at a pressure of about 110 volts. The furnace is charged almost up to the level of the electrodes with cold scrap iron, and these are then adjusted to give a suitable length of arc. When the furnace is cold the arc is only about 4 in. in length, but it increases as the temperature rises to about 12 in. long. It is evident that a considerable portion of the heat generated is radiated to the roof or dome of the furnace, and were this made low as in other arc furnaces it would soon be melted away. It is therefore made high in order to avoid this difficulty, but at the same time a greater surface is exposed to radiation losses. Stassano furnaces are usually made to rotate, as of course there is no electromagnetic mixing of the charge. Furnaces of the earliest design rotated completely round an axle slightly inclined to the vertical. This involved several difficulties; among them that of making a good electrical contact for the large current between moving surfaces. In the later designs, the arrangement shown in Fig. 3 has been adopted, the complete rotating movement being altered to an oscillating movement which allows the electrical contacts to be rigid. The Stassano furnace has the advantage of a very steady load when compared with other arc furnaces, especially when used for melting cold materials. It is also easy of regulation, but has not a high heat-efficiency owing to the large radiation losses. [illegible] this type of furnace, as compared with the advantage of complete tilting of practically all the other types. When the tap-hole is used, the coolest portion of the metal from [illegible]

[illegible]

[illegible] more [illegible] than in the case of the Stassano furnace.



[illegible]

Coming now to the second and more important class of arc furnace, in which the current in addition to passing through the arcs passes through the charge itself, it would be as well to commence with the earliest of these furnaces, namely, the Héroult furnace. This was originally made to take single-phase current. The general arrangement of one of these furnaces is shown in Fig. 4. The current enters by one of two upper electrodes, passes first through the arc gap, then along the surface of [illegible] by means of the other electrode to the [illegible] the important drawback of requiring single-phase current, which means that the existing power supplies have, in [illegible] rather inefficient motor-generator set to either single-phase low-tension current at the furnace voltage or else single-[illegible] tank of the furnace [illegible] are provided un[illegible] furnace tilts. This tilting may be effected [illegible] in the small sizes, or by an hydraulic ram or a[illegible]

driven tilting gear. The electrodes are carried in special holders which are usually water-cooled and attached to large brackets travelling up and down between vertical guides at the back of the furnace. These are driven by means of rack and pinion gearing, which is usually motor-operated, the motors being controlled by Thury regulators designed to work at constant voltage for this type of furnace. The furnace hearth is made of layers of either magnesite or dolomite mixed with tar and thoroughly rammed together so as to form a solid bottom similar to that of the basic open-hearth furnace. The side walls are usually of magnesite brick, whilst the roof, which is detachable, is composed of silica bricks held in a steel frame provided with two holes to allow for the insertion of the electrodes. There is usually a water-cooled ring resting on or embedded in the roof round the electrode holes.

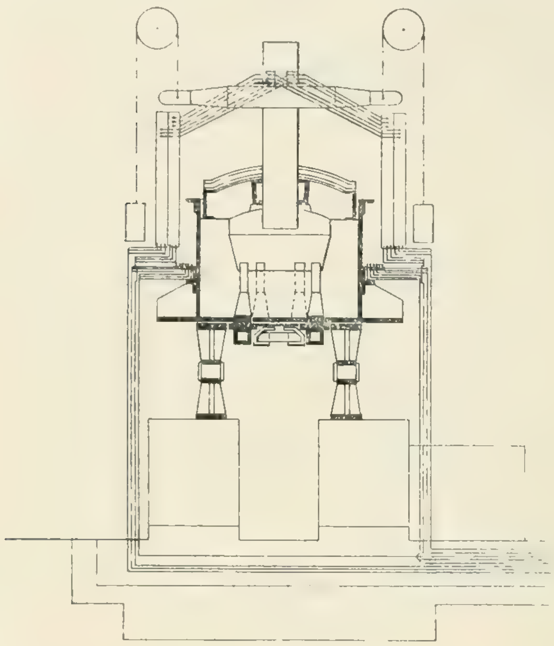


FIG. 5.—Girod Furnace.

Latterly, a 3-phase Héroult furnace has been introduced suitable for construction in the larger sizes. Its general design is similar to that mentioned above except that there are, of course, three electrodes instead of two. Each electrode carries a separate phase, and the arrangement has the advantage that the usual 3-phase supplies can be transformed by means of three single-phase transformers down to the furnace voltage. The Héroult furnace has the disadvantage of surface heating. In other words, the upper layers of the charge are always much hotter than the lower, and this is undesirable when making high-quality steels requiring considerable quantities of ferro-alloys, as these sink to the lower portions of the furnace, where they melt only with difficulty. Otherwise the Héroult furnace is very efficient when melting cold charges, but the single-phase type is open to the objection that the fluctuations in the power taken are very serious, as it is obvious that if the arc underneath one of the electrodes is broken, for example, by the falling away of melting pieces of the charge, the whole load is instantly thrown off the supply system.

The Girod furnace is typical of the second class of arc conduction furnaces. Its principle is shown in Fig. 5. There are one or more vertical electrodes according to the size of the furnace and of like polarity. Embedded in the bottom and forming an integral part of the furnace are water-cooled steel studs, which project slightly above the bottom of the hearth and make contact with the charge itself, and so convey the current back to the generator. Apart from the difference in the bottom of the furnace, the general mechanical arrangements are similar to those of the Héroult type. The bottom electrodes are very interesting, and have been at different times severely criticized. On the whole, however, by suitably regulating the supply of cooling water they may be kept from melting away, or on the other hand from seriously cooling the bottom of the furnace. Published figures show that when melting cold materials the furnace bottom will last for 120 to 160 operations, which is a fairly satisfactory result. With these metal studs at the bottom of the furnace, fettling is very difficult, as care must be taken not to insulate them from the charge. The result of not being able to fettle the bottom is that the size of the hearth gradually increases, and of course radiation losses become greater owing to the thinner walls and bottom. Single-phase current is always used, and here again the drawback of using the motor-generator set compared with static transformers is again in evidence. In this furnace, apart from inductive and resistance losses in the leads and the resistance losses in the carbon electrodes, practically the whole of the power is consumed in the arc itself, as the resistance of a mass of fluid metal several square feet in area and probably a foot or so in depth is practically negligible.

It is understood that although this arrangement of steel studs in the furnace bottom is essential to the Girod system, yet it has its disadvantages, and in order to overcome these and at the same time obtain a furnace which will work from the usual supply mains through static transformers, the Electro-Metals furnace was designed a few years ago. The original inventors were the three Swedish engineers, Messrs. Grönwall, Lindblad, and Stålhane, who have designed and developed the Elektrometall shaft furnaces for the reduction of iron ores which have proved such a great success in Sweden. The development of their steel furnace has taken place mainly in this country where, after considerable time spent in experimenting, the furnace has now been thoroughly established for commercial working. Fig. 6 shows the main principles of the furnace. Two-phase low-pressure current is employed and this is obtained from a 3-phase system through two single-phase transformers using the well-known Scott connection. There are two upper electrodes each carrying a separate phase, whilst in the bottom of the furnace beneath the basic lining is a third electrode which acts as a neutral return common to both phases. Thus the current flows, on each phase, starting from the transformer, along the copper leads to one of the upper electrodes, through this, across the arc gap, through the metallic charge, and thence through the basic lining to the bottom electrode, which consists of a layer of special carbon mixture covering the bottom

[illegible]

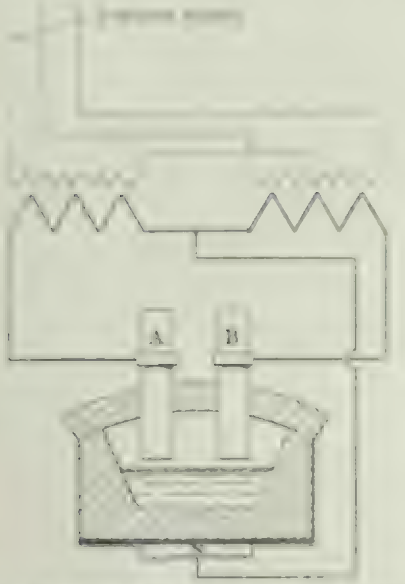


Fig. [illegible]—[illegible] of Electro-Metals Furnace.

[illegible] immediately below the arcs evenly throughout the whole [illegible]

The general construction of the Electro-Metals furnace [illegible] designed to avoid bulging when hot. The electrodes are [illegible] fastened to a carriage which runs over and between two vertical channels. The carriage is driven by a vertical screw in the centre of these channels, and the screw in turn is actuated by a worm wheel and worm coupled to a small electric motor. At the back of the furnace there is a large door for the charging and [illegible] when removing it from the furnace. At the front of the furnace there is another spout through which the whole of the charge is poured into the ladle. The tilting gear [illegible]

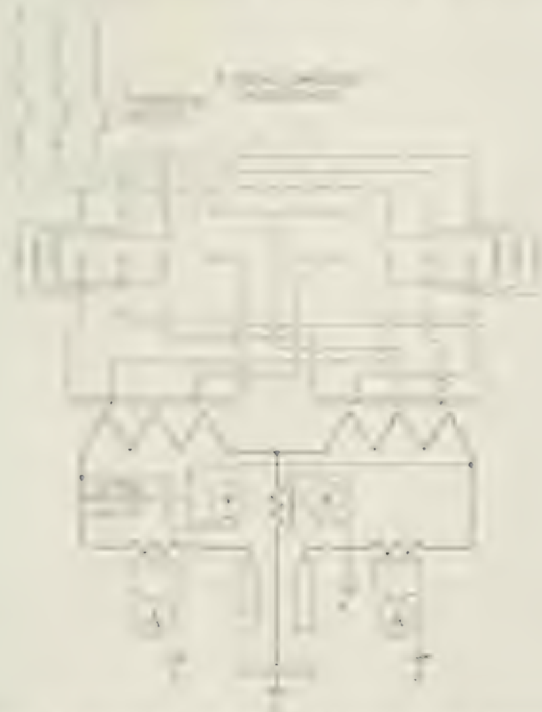


Fig. [illegible]—Electrical Connexions of [illegible] Furnace.

a short time. The lining of the furnace is similar to that of most other furnaces except that over the bottom plate there is a layer about 1½ in. thick of carbon mixture, which when the furnace becomes hot is baked into a [illegible] similar in composition and structure to the [illegible]

[illegible] two circuits, each of which passes to a suitable oil switch, [illegible]

nected to tappings on the high-pressure side of the transformers, one tapping to give a high pressure of say 80 volts and the other to give about 50 volts. These two switches are interlocked so that only one of them can be put in at one time and the change from the high to the low pressure is made simply by tripping one switch and then moving along the interlocking bar and putting in the other switch.

The instruments installed are placed on the low-pressure side and consist of an ammeter on each phase and one on the neutral, which are operated by series transformers placed round the low-pressure busbars. A voltmeter is installed which gives by means of a 3-way switch the pressure between either of the two phases and earth or the pressure across the two phases.

As is the case in all arc furnaces, the current flowing in the furnace is controlled by raising and lowering the electrodes, thus increasing and decreasing the size of the arc gap and so making the resistance greater or less according as the current is smaller or larger. In small furnaces this adjustment of the electrodes is made by hand, but in the larger ones where the moving portion of the electrode and holders, etc., weighs several hundred pounds a motor has to be used. These motors work in conjunction with some form of automatic regulator, preferably of the Thury type. The latter are connected to series transformers on the phase leads, and by means of rheostats in the secondary circuits are set to regulate the current on each phase at a definite figure. When the current falls below this figure the arm of the regulator swings over and makes contact with the leads to the motor, so giving a series of impulses to the vertical screw, thereby lowering the electrode until the current increases to the proper value. Conversely, when the current become too great the regulator reverses the rotor and raises the electrode, thus diminishing the current flowing. In addition to the control of the electrode motors by means of the automatic regulators, a direct control is effected by tramway-type controllers, which in conjunction with speed regulators enable the electrodes to be quickly hoisted out of, or lowered down into, the furnace.

A description of the working of a typical charge may not be out of place as some of the difficulties which designers have to meet in electric furnace work are only brought out clearly by a consideration of the actual work that has to be done in the furnace itself. Assuming then that the previous charge has been "teemed" and the furnace fettled, the cold scrap is thrown into the furnace hearth. This scrap, which is preferably of steel or wrought iron, is usually of very common quality and contains anything up to 0·1 per cent of both sulphur and phosphorus. When the furnace is charged the current is switched on and the electrodes lowered down until an arc is struck between them and the upper portion of the charge. The automatic regulators are then switched on and the rheostat is set to give the required current. In the case of a 4-ton furnace, which the author proposes to take as typical, the melting current is about 5,500 amperes, the pressure at this load being about 75 volts on each phase. The heat of the arc soon melts a large hole in the charge underneath and round each electrode, which continues to travel down as these holes become deeper until a bath of fluid metal is formed in the bottom of the furnace. This bath gradually increases in depth owing to other portions of the charge melting into it and the electrodes gradually rise with the level of the metal. By the time they have risen to the usual working level of the bath any unmelted portions of the charge are detached from the sides and pushed within the hot metal in the centre. During the melting the slag is added consisting of a mixture of lime, fluorspar, sand, and either iron ore or hammer scale. This slag, owing to its lower density, floats on the top of the molten metal and the chemical actions of refining take place. The carbon in the scrap is oxidized by the iron oxide in the slag and is given off in the form of carbon-monoxide, which rising through the metal, gives the appearance of boiling. This boiling serves to bring the slag and metal into more intimate contact. The silicon and manganese in the scrap are oxidized, and their respective oxides dissolve in the slag. The phosphorus is oxidized and, in the presence of the lime in the oxidizing slag, is formed into a phosphate of lime, which enters into the slag. A portion of the sulphur is also oxidized and passes away as a gas. When sufficient time for these reactions to take place has elapsed, the current is switched off and the furnace tilted backwards until most of the slag has run off through the small spout at the back of the furnace into a slag bogie. The remaining portions of the slag are pulled off by means of rabbles until the surface of the metal is practically free from slag. In this way phosphorus is removed. The recarburizing additions are made to give the required carbon to the steel and another purifying slag is added. This consists of lime, sand, and fluorspar, and quickly melts when the current is switched on. The pressure is now reduced by changing over from one switch to the other, and the current at the same time is lowered to about 2,000 amperes. The phosphorus as stated above has been removed, but there remains among the injurious constituents in the metal the bulk of the sulphur and in addition a certain amount of oxide of iron which has come from the oxidation of the scrap during the melting and from the oxidizing slag that is necessary for the removal of the phosphorus. The metal must thus be freed from this oxide and from the sulphur. The oxide of iron in the metal is also soluble in this new slag, which takes it up until the solvent powers of the two fluids are equal. The oxide is then removed from the slag by means of the addition of finely-divided carbon in the form of powdered anthracite, which reduces the oxide of iron in the slag and at the same time makes a reducing atmosphere of carbon monoxide inside the furnace. In these circumstances the oxide of iron in the steel is continually passing into the slag as the carbon reduces it, and in this way the whole of the metal is gradually freed from its oxide. At the same time, under the reducing conditions and under the influence of the chemical composition of the slag, the whole of the sulphur is automatically removed from the metal into the slag. Thus in this way the metal is purified into high-grade steel.

These reactions result in some very interesting changes in the slag itself. At the commencement of the refining this slag is black in colour, but as the oxide of iron is removed from it, it becomes gradually white, and on cooling down to atmospheric temperature falls gradually into a white powder. The steel being now purified is ready for "teeming" into the ladle, its composition being

[illegible] and manufacturing the same products, the question of the relative merits of the different types of furnace from the point of view of energy consumption could be settled. [illegible] furnace to install, the questions of the initial cost of the plant, its suitability for running off existing power supplies, the cost of repairs to the furnace, and the ease with which these can be carried out, are all points which [illegible] possible by "killing" the steel with silicon and manganese (as is done in the open-hearth furnace) to produce a steel in less time and using less energy than when employing [illegible] time the steel produced, although showing a satisfactory [illegible] tests as is the steel upon which more time is spent and more power used for deoxidation in the best manner. Naturally the purpose for which the steel is to be used determines the nature of the refining process which ought to be employed; and mild steel suitable for steel castings can be produced much more cheaply than the highest [illegible] the furnace has an important bearing upon the energy [illegible] capacity. However, [illegible]

[illegible] furnaces are largely used for refining fluid metal taken [illegible] more impure, so tha[illegible] for some years and have up to the [illegible] to that employed in the ordinary way after the charge has become melted. A dephosphorizing slag is added to the metal as soon as it is poured into the furnace; and after this has been allowed to work it is removed, the finishing [illegible]

[illegible] to the open-hearth and Bessemer processes, being used to melt ferro-manganese additions, as it has been found that the saving in the amount of this alloy required more than pays for the cost of melting it electrically.

In this country the field for the electric steel [illegible] producing a superior product. Abroad, however, [illegible] in those regions where water power is plentiful and electrical energy can be produced very cheaply, it is poss[illegible] in fact probable, that electric furnaces will be used to produce steel in large quantities instead of employing the older class of fuel-fired furnaces.

DISCUSSION.

Peck. Mr. J. S. PECK: A few years ago when the electric furnace was mentioned as being a possible means of refining steel, it was hoped that if it did not revolutionize the manufacture of steel it would in any event enable a high quality of steel to be produced at a comparatively low cost from a poor quality of metal. The electrical manufacturer was specially hopeful because he foresaw good business ahead. The anticipated results have not been wholly realized, and I should be interested to hear from the author why the introduction of the electric [illegible] 15-ton electric furnaces for refining Bessemer steel were introduced in America, but I have not heard recently of [illegible] no supply engineer wishes to have on his [illegible] furnace appears to me to have a great advantage bec[illegible] paratively small sizes, while many other types hav[illegible]

Mr. Peck. the fact that there are a number of low-tension coils in parallel, and it is also necessary to bring out tappings from the high-tension windings in order to vary the voltage applied to the furnace. If the tappings are cut out in the ordinary way from part of the high-tension winding it leaves an unsymmetrical relation between the primary and secondary windings, and very heavy local currents are likely to flow from one secondary coil into the other. There are a number of ways of overcoming those difficulties, but in general it is necessary to arrange the windings so as to keep the relation as symmetrical as possible between the primary and secondary windings. I believe this is the first paper on this subject which has been presented before the Institution, and while it gives an extremely clear description of the principal types of furnaces now on the market, it seems to me that in order to make it complete, and in order to make it a valuable work of reference for the members, it should contain more information than is actually given. Some of the information that I should like to see included is as follows:—The largest size of electric furnace that has been made so far. The total kilowatt capacity of electric furnaces now in use. Is the rate of increase rapid, or slow? Data as to the voltage, current, number of kilowatt-hours, and the time required for making different classes of steel under various conditions. The price at which electricity must be sold in order that the working of steel furnaces under various conditions for the production of steel may be a commercial possibility.

Mr. Faye-Hansen. Mr. K. M. FAYE-HANSEN: It seems to me that from the electrical engineer's point of view the best type of electric furnace is the induction furnace. It is possible to make a pure induction furnace for 3-phase working, and it is possible to arrange it in such a way as to secure a fairly reasonable power factor for reasonable sizes and frequencies. But when we bring the suggestions to the notice of the steel-makers we always find that there are difficulties in the way, as mentioned in the paper, such as that the steel-maker must have good working room and also a high temperature of the slag for getting the necessary chemical reaction. One thing which limits the freedom in the design of an induction furnace is the "pinch effect," which prevents the bath from being a wide and shallow channel. Most of the commercial electric steel furnaces are made on the arc principle. With regard to the arc furnace, almost the first consideration from the supply company's point of view is to get a steady load and at the same time to secure a reasonably good power factor. Those two requirements are really conflicting. For instance, for a small steel furnace a power factor of 0·97 might be obtained, but one would then have to build the transformer and to make the leads between the transformer and the furnace with as little reactance as possible. In that way one would get a good power factor. But if we do that the currents taken when a short-circuit occurs in the furnace are very large and will be objected to by the supply company. For a small furnace we can by proper design and lay-out obtain the power factor which we wish from the point of view of not getting too big short-circuit currents. For instance, if one makes a furnace to have a power factor in the neighbourhood of 0·9 the short-circuit current will be about double full-load current. When we come to the very large furnaces, however, it is impossible to obtain a high power factor because of the unavoidable inductive effects of the leads and in the loop round the furnace. In fact one comes to certain limits of size of furnaces for any frequency depending upon the voltage that one is willing to use on the arc. It is possible to raise the limit by such means as interleaving the leads to the furnace, bringing them in from two sides so that each loop only carries half the total current, etc. But still the frequency of 50 will be too high for very large furnaces, though it is quite satisfactory for the sizes now being built. I should like to ask the author regarding the advantages in the Electro-Metals type of furnace of getting the current to the bottom of the furnace, whether it is of great importance during the whole period or only towards the end of the charge when the final refining takes place. If it is of great importance only during the refining part of the process there are other arrangements than the Electro-Metals furnace which might suggest themselves as being improvements. Assuming that it is necessary—or if not necessary, at least useful—to have the current at the bottom during the whole time of the charge, I think that the present arrangement of the Electro-Metals furnace will prove to be the best for steel making.

Mr. Rosser. Mr. G. L. ROSSER: I should like the author to state whether only basic steel is manufactured in the electric furnace, and if so whether the basic steel so manufactured is superior to the steel manufactured in the Siemens open-hearth acid process. Have the two steels—*i.e.* steel made in the electric furnace and steel of similar analysis made by the Siemens open-hearth acid process—been tested for tensile strength, yield, elongation per cent, and reduction of area, and subjected to bending and shock tests? If the steel made in the electric furnace proves to be superior this should be taken into account, as the raw material used in the electric furnace would be much cheaper than that used in the Siemens open-hearth acid furnace. I suggest that the author should refer to this point in his reply. It would be extremely useful to know the cost per ton of steel made in the electric furnace. This price should include the cost of raw material, scrap, dephosphorizing agents, etc., and also the consumption of electrical energy. A price per ton should be given separately, including depreciation of furnace, repairs, and renewal of carbons. Such figures would give the steel manager the opportunity of checking them against the figures already obtained in making steel in open-hearth furnaces by both the acid and basic processes. Is it possible to over-oxidize the steel in the electric furnace or to get a "cold tap"? On page 539 the author says, "A small addition of aluminium or an alloy of aluminium is usually added at the end in order to remove any traces of gases which may remain in the steel." Is not the usual practice to add such aluminium, not in the furnace, but in the ladle? On the same page is the phrase "from which it is teemed into the ingots or castings." I think the author means the moulds; the ingot is the metal which solidifies after it has been teemed.

Mr. Wilkinson. Mr. H. T. WILKINSON: I ask for information more from the point of view of the supply engineer. I should like more definite figures of the kilowatt-hours per ton. What is the maximum demand for a 2-ton or 4-ton furnace, and over what period will the demand occur, or rather what will the load curve look like? It would have been interesting if the author had given a recording-ammeter chart to show what happened. I should imagine the load is

[illegible] the electricity supply station, and also for another depart- [illegible] have not been able to use, and the conditions are such that [illegible]

Mr. [illegible]: We have found difficulty in [illegible] in this country steels of a particular quality; they are produced on the Continent of a higher grade than is manufactured here. One point which has specially impressed [illegible] to be quite unable to produce similar steel at different times. [illegible] wards when they are called upon to supply steel of equal quality in bulk they are unable to do it. That has happened not once but many times. They are quite willing to take the steel back and to show customers their [illegible] analysed the steel most carefully and examined it micro- [illegible] suitable steel they will spend a good deal of time in analysing it, and at the end they are unable to reproduce it with the same properties. I think our electrical tests have proved far more searching than chemical analysis or any of the physical tests that can be applied, and the result is that we find differences which they are not able to appreciate. I do not know much about steel manufacture, but I believe that the firms engaged in it are apt to have the mixing done by foremen who have grown up with the work and who have had great experience. These foremen, I think, treat their material in much the sort of way that a domestic cook goes about her work; that is to say, they have rather a contempt for scales, weights, and so forth, and prefer throwing in handfuls of material according to their own experience. I know this is not quite the case with some firms who have introduced better methods of working and are trying to become more searching in their analyses, but the point is that they still get enormous differences in steels which they wish to make exactly the same. I do not know whether it is due to the ordinary furnace methods which they adopt, or to impurities in the materials that they procure. I have a suspicion that their chemical analyses are not yet perfect enough and tiny quantities of certain impurities get in and upset matters. Or it may be that after they have obtained pure materials small quantities of impurities which are specially [illegible]

[illegible] furnace. A lot of [illegible] either the methods were very unscientific or the merits of [illegible] manufacturers will be able to get over some of the un- [illegible] reasons why manufacturers who have tried these furnaces have abandoned them later?

[illegible] chiefly of an interrogatory chara[illegible] is required in order to render the paper of great future value. Mr. Peck has already put forward some of the queries which I had noted. The first of them is whether electric furnaces are actually in use in this country to any considerable extent. The extension of their use is obviously [illegible] brought to a level which will justify their employment— [illegible] mation as to the price of electrical energy that will render them commercially practicable for different classes of work. Mr. Faye-Hansen has mentioned the subject of power factor. I am rather surprised to find that he says difficulties may arise from the reactance of the leads. I have seen a number of Swiss plants with arc furnaces for the fixation of atmospheric nitrogen, in connection with which there have been difficulties with the power factor, but from exactly the opposite cause. In some cases I believe the power factor is approximately 0·2 leading, though I have not got the exact figures. I should like to know what the author's experience has been with the electric steel furnace, whether the presence of iron more than counterbalances the tendency of t[illegible] to produce a leading current. The pow[illegible] of the points which will influence the choice of a particular type of furnace for any given class of work. On page 538 the author says, "These motors work in conjunction with some form of automatic regulator, preferably of the Thury [illegible] has been that with very large current variations it is not as [illegible] instance, the Güttinger, or Brown-Boveri regulator as [illegible] rapidly when large variations are experienced.

[illegible] have been more interesting if the author had [illegible] the costs of working of each type of plant so that intending

Mr. Panton. users might have some sort of guide when adopting electric furnaces in this country. He also might have brought out the merits of electric steel castings over ordinary grades now in use, and the reason for adopting the method of casting referred to. I visited some nine months ago at Sherbrooke, Canada, a works where electric furnaces were entirely used for smelting ordinary steel and manganese steel castings, including electrically-smelted bronze bearings and ferro-manganese brake blocks, all for railway and tramway use. The type of plant used was similar to the Héroult furnace described by the author, but of the 3-phase type, wherein the three vertical carbons were raised or lowered by hand gear into the square steel case, which was lined with special bricks, dipped in tar, and mounted on curved rails for tilting purposes, the tilting being effected by hand power and levers at each end. Water cooling was provided round the electrode holes, and the electrodes were 7 in. in diameter and about 3 ft. long, screwed male and female for continuous feeding. This represents a 2-ton furnace, which invariably receives a charge of 35–30 cwt. of metal. The power was supplied by a waterfall 7 miles distant, and was transmitted to the works at a pressure of 6,600 volts, being there transformed down to 110 volts. The time taken for a cold charge was 5 hours, but as the plant invariably works night and day the remaining heats took 4 to 4¼ hours. I myself experienced considerable delay in striking an arc to the scrap rivets, etc., but when the arc was struck the ammeter on the high-tension side read 40 amperes, so that the start represented 264 kilowatts, or 2,400 amperes melting current on the low-tension side. For a 4 hours' charge, the current consumption diminishing with time, 900 kilowatt-hours were taken for 30 cwt. of metal in the ladle. This is a somewhat better result than the author's figures, especially when I say that the cost of energy per unit was 0·1d., the energy being purchased in bulk. Compare this with the cost of energy in this country, and it will be seen that electrically-smelted steel can, in ordinary times, be placed on the market here at lower prices than those at which it can be produced in Sheffield or Newcastle. With regard to the quality of the product, the chief difference between the castings made by the new and old processes is that owing to the low percentage of carbon in electric castings many are used without annealing. Higher qualities of steel can be produced electrically than by other processes. I fully agree with the author that there is a splendid field for electric steel rails, especially of the manganese or ferro-manganese type. Care should be taken not to reduce the conductivity of rails used for electric railways and tramways, and especially where magnetic slipper brakes are in use, as manganese steel made by the electric process is practically non-magnetic, more so than manganese steel made by the ordinary process.

Mr. Robertson. Mr. T. D. ROBERTSON (*in reply*): Mr. Peck raised the interesting point: How is it that the introduction of electric furnaces has not been as rapid as was predicted? Many members will doubtless remember that seven or eight years ago the future of the electric furnace was painted in very bright colours, mainly by people who were exploiting various types of furnaces, and the result was that when electric furnaces were built and put into operation much experimenting had to be done and alterations made in order to make them serviceable on a commercial scale. Unfortunately these experiments had usually to be made at the expense of the firm who had purchased the furnace and who thus became prejudiced against electric furnaces in general. The result of such experiences was that steel makers naturally became sceptical of the claims advanced by furnace makers, and it is only now that these prejudices are wearing off owing to the fact that there are at the present time many electric furnaces in satisfactory operation. Mr. Peck mentioned 15-ton furnaces. These have been used in America, chiefly for refining fluid Bessemer metal for the production of steel rails. The United States Steel Corporation installed them mainly with the idea of making experiments on a large scale with big electric furnaces for this work; they have produced a lot of rails which have been put down and are at the present time undergoing tests. There is every indication that the results of those tests will be very satisfactory, and I think we may soon look for a big development in the United States in the use of large furnaces for refining crude Bessemer steel.

Mr. Peck also emphasized the point that it is a big advantage to have a furnace which will utilize 2-phase or 3-phase high-tension supplies rather than one which has to take single-phase current. This advantage is so marked that the Héroult furnaces are now made in the small sizes to take 3-phase current instead of single-phase which has until recently been the usual practice. The largest size of electric furnace that has been put down is, as far as I know, a Girod furnace of 20 tons' capacity which has been installed in the south of France. The transformer capacity required for electric furnaces does not increase directly with their tonnage. That is to say a 10-ton furnace does not need twice the transformer capacity that is needed for a 5-ton furnace, the kilowatt capacity per ton being less with the larger sizes.

With regard to the price at which electricity must be obtainable in order to make the working economically satisfactory, this is really dependent upon the quality of the product that is to be turned out. If cheap material suitable for steel castings is to be made, the price of power will have to be lower than for the manufacture of the highest grades of tool steel. Generally speaking, if power can be obtained at 0·5 or 0·6d. per kilowatt-hour the electric furnace will compete successfully with other processes for the making of small steel castings, and it is certainly the most economical apparatus for the making of the highest grades of tool steel.

I can quite understand that from an electrical engineer's point of view the induction furnace seems almost an ideal arrangement, but, as Mr. Faye-Hansen pointed out, steel makers object to it. It is essential in steel making to be able to get at all parts of the furnace conveniently with working tools and to be able to make additions to the slag or remove it if necessary. In the induction furnace the heat is generated within the metal composing the ring round the transformer. Consequently the slag, which lies on the top of the metal, receives all its heat from the metal and is therefore always cooler than the metal because the upper surface of the slag is exposed more or less to the atmosphere during the whole of the process. For this reason refining slags that have a high melting point cannot be employed. In the arc furnace the conditions are

[illegible] point [illegible]

[illegible] total [illegible] is very much reduced. I may say that these short-circuits arise during the melting, when the metal in the neighbourhood of the electrodes has almost reached the melting point and, becoming soft, suddenly falls against the electrode, forming a short-circuit and resulting in a sudden overload, which is obviated by raising the electrode.

Another point raised by Mr. Faye-Hansen is the [illegible]ty or the necessity of having current passing [illegible]gh the bottom of the furnace during the whole of the working period. It is necessary for this to be the case with the 2-phase arrangement in the Electro-Metals furnace. This current passing through the bottom is [illegible] temperature of the different parts of the metal.

Mr. Paxton asked: Does the cost of power in this country justify the adoption of electric furnaces? The answer is that this question must be decided by local conditions. Given a certain cost for power, the manufacturer who proposes to put down an electric furnace must decide whether the prices that he will obtain for his product, or the improvement that he will obtain in the quality, will justify the extra expense of electric heating.

It is never possible to obtain a leading power factor with an electric steel furnace because there is always considerable inductance in the leads owing to their proximity to iron or steel in various shapes and forms; in fact, the furnace casing itself has a considerable amount of inductance.

The point in regard to the Thury regulator is [illegible] their electric furnaces because they believe this is the only [illegible]

[illegible] Mr. Thomas [illegible] steel [illegible] quality throughout and [illegible]

[illegible] that during the manufacture the [illegible] which is present in all [illegible] crucible, this oxide is got rid of by adding de-oxidizing [illegible] of skill which is imparted to the manufacture of crucible steel is higher than that imparted to the manufacture of electric steel. It is very easy to make bad electric steel [illegible]

[illegible] melting of a charge. Take, for example, a 2-ton furnace in which the total time between teeming one heat and [illegible]

Mr. Robertson.

approximate figures but they illustrate the way in which the load is divided up. Taking the case of a furnace working continuously—that is to say 24 hours per day for five days per week, and allowing time for making repairs, about 20 charges will be obtained per week, and assuming 45 working weeks per year, the load factor works out at about 40 per cent. The power factor depends entirely upon the way in which the leads are arranged, but in a 2-ton furnace the power factor will be approximately 0·9. I should mention that in the six hours there will be an hour taken off in the charging, in the removal of the slag, and in the fettling of the furnace after the charge is teemed.

Mr. Rosser's question dealt with basic steel. I think with one or two exceptions all electric steel is made on a basic bottom. In Germany two or three years ago experiments were carried out in a small Héroult furnace making steel on an acid bottom, but of course in that case there is no dephosphorizing. It is simply a question of melting high-grade raw material. Owing to the deoxidation of the electric steel it is, when properly made, superior to the best acid open-hearth steel. The reference in the paper to aluminium is rather ambiguous. Aluminium is of course added to the metal as it runs out of the furnace into the ladle.

Mr. Panton has given some interesting figures about a small Héroult furnace working in Canada on a variety of products. The difficulty in striking an arc, to which he refers, I have never experienced with the Electro-Metals furnace. It would be a great advantage if we had current at 1/10d. per unit for electric furnace purposes in this country, as the cost of current is a large item in the cost of making electric steel. I am glad the point was mentioned about low-carbon electric steel castings, because that is a point in favour of the electric process. Steel castings made in the crucible—and large quantities of small steel castings are so made—cannot be melted with very low carbon, consequently they are rather hard for machining afterwards and have to be annealed. With the electric furnace the carbon can be brought down as low as desired and many castings can be machined up without any annealing.

Mr. Robertson.

In response to several requests made during the discussion for data relative to the cost of manufacturing electric steel, I give below some typical working costs for Electro-Metals furnaces of varying capacity making steel suitable for high-quality steel castings by melting common steel scrap, removing phosphorus and sulphur and thoroughly deoxidizing.

CAPACITY OF FURNACE.

	25 Cwt.	2½ Tons	5 Tons
Number of casts per week ...	25	20	18
Number of tons per week ...	31·25	50	90
Number of tons per year (45 working weeks)	1,406	2,250	4,050
Transformer capacity, kw. ...	300	500	900
Current consumption per ton, kw.-hours	850	800	750
Electrode consumption, lb. per ton	45	40	35

COSTS PER TON OF METAL IN THE LADLE.

	£	s.	d.	£	s.	d.	£	s.	d.
1. Scrap at 55s. per ton (allowing 7 % loss)	2	19	3	2	19	3	2	19	3
2. Current at 0·5d. per unit	1	15	5	1	13	4	1	11	3
3. Electrodes at 1¾d. per lb.	0	6	7	0	5	10	0	5	1
4. Labour	0	6	6	0	5	8	0	4	1
5. Materials for slags ...	0	1	9	0	1	6	0	1	2
6. Alloys adding 0·25 % Si and 0·75 % Mn...	0	4	6	0	4	6	0	4	6
7. Repairs and Maintenance...	0	8	7	0	5	10	0	4	6
8. Ladle costs	0	2	11	0	1	9	0	1	5
Total	£6	5	6	£5	17	8	£5	11	3

Management, laboratory, and overhead charges are not included.

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TELEPHONE TROUBLES IN THE TROPICS.

By W. Llewellyn Preece, Member.

[illegible]

[illegible] responsible for the maintenance [illegible] those who live in such countries to find the night temperature dropping to even 80° F. The main troubles are due to the damp, and to the many natural effects caused by [illegible] varies between 80 and 90 per cent it is possible to appreciate the reasons for the telephone engineer's more or less emphatic complaints. When, in addition, it is realized that this damp heat produces a marvellous growth of vegetation—so thick that along the sides of the country roads there are actual walls [illegible] more trying, then one is in a position to understand the difficulties and to sympathize with the tropical engineers.

[illegible]

[illegible] For instance, in some parts it is [illegible] up against a telegraph or telephone line; they have not [illegible] poles and the lines. In this [illegible] beasts!

The main reasons for bringing this paper to the notice of members of the Institution are to impress upon them the [illegible] those parts, and finally with the hope that in the discussion engineers in those climes may obtain many useful hints which will go towards relieving their hard lot.

[illegible] in turn, the sub- [illegible]

paper may be of some interest to all branches of the electrical engineering profession.

Instruments.

So far as white ants are concerned, we find that the use of teak practically prevents their ravages. The author has been told that in the Gold Coast this pest is so voracious that it attacks teak as willingly as any other wood; but he is inclined to think that this is an exaggeration, and he has certainly not heard of any telephone set being devoured by these insects, or even attacked. The white ant is not, however, the only troublesome insect. On the table is an instrument to which a swarm of bee-like insects of Nigeria took a great fancy to use as a hive. Their entrance was the slot of the switch-hook, and the comb formed in the interior will be noticed. The comb was cleared out many times, but each time it was re-formed by the insects, until in despair the engineer had the whole apparatus removed. The spider is a real pest all over the tropics; it delights to retreat into the telephone case and to build for itself a nest therein; so that it is no uncommon experience to find instruments entirely *hors de combat* from the diligent work of this insect.

To circumvent the insect plague it is essential that these telephone cases should be sealed up as closely as possible. The switch-hook should carry a brass plate which keeps the slot in which the arm works entirely covered. It is also desirable to have no terminals above the instrument, but to take the conductors through holes into the case and seal up these holes. Besides this, the internal wiring should be made as simple as possible; the wires must not be bunched together, but well stapled to the body of the instrument in separate ways. It is generally found that enamel insulation with a silk covering is very suitable, though, as will be seen later on, enamel insulation does not always give satisfaction.

How many engineers in this room would dream that in a tropical climate the ebonite sheath of a receiver would become soft and pliable? Yet on this table there is a receiver from the West Indies the sheath of which was softened with the heat, and when clasped behaved like "plasticine." Many others did exactly the same. Of course this is easily remedied by using blocked brass sheaths covered with enamel; but one only learns such things by experience. In another tropical country a lot of trouble was caused by the insulating block which carried the contact springs in a capsule transmitter of a micro-telephone being warped by the damp heat, so that both springs touched the metal case of the capsule and short-circuited the microphone.

Happily, in most of the tropics the faults in the subscribers' instruments caused by lightning are very few, and so long as the engineer takes the precaution to fix the lightning protector at the point where the wires enter the house little trouble need be feared. Where the casual custom of fixing them near the instrument is followed it is not uncommon—as at least one engineer learnt to his cost—for the building to be set on fire. Until the protectors were fitted to the eaves of the roofs outside the building walls, the telegraph offices in Northern Nigeria were repeatedly burned down through lightning.

The only other trouble likely to be experienced with the subscriber's instrument is that due to maltreatment by the subscriber himself. It may be said that the same trouble is equally prevalent here, but the author doubts whether it is quite so bad. The tropical climate is not conducive to an equable temper. People naturally get irritable, especially if they have lived in that trying climate for some years. Even in this country the vagaries of the telephone cause occasional outbursts; there it is far worse, especially as the subscribers know that the operators at the exchange are usually of a lower race not possessed of much mental power. Moreover, the instrument is largely used by their boys—*i.e.* native servants—and that practice accounts for many faults. Nevertheless, the most absurd fault that the author has ever heard of was due entirely to the stupidity of a white man. This man, the owner of a large rubber estate, complained bitterly time after time of his instrument; the native inspector was constantly in the house tampering with it, without much success. Finally the engineer himself went to see the instrument and discovered that this ingenious subscriber was in the habit of using the mouthpiece of his micro-telephone, which hung from a wall-instrument by his desk, as a cigarette ash tray. In fact the microphone was full of tobacco ash.

The late Sir William Preece often asserted that nine-tenths of telephone troubles were due to the ignorance of the subscriber. The author is sure that the tropical engineer would heartily agree.

Exchange Switchboard.

There has been, for some years past, very considerable discussion concerning the question of what type of board should be used in the tropics; and until lately the craving of the tropical engineer was to have the up-to-date central-battery system. There is at present a tendency to progress even beyond this and make a demand for an automatic system. From many points of view either of these systems would be a considerable boon to all concerned. There is, however, one obstacle in the way, which in the author's opinion is at present insuperable. This hindrance he proposes to deal with more in detail in connection with line faults; but he can say here that the maintenance of really satisfactory insulation on overhead lines is almost impossible in the tropics, and if with this poor insulation a pressure of 24 or 40 volts was applied to the line, even moderately fair working of the system would be extremely doubtful. The author has therefore set himself strongly against the central-battery board, unless a Government is prepared to place the whole system underground—which is usually prohibitive in cost seeing that some of the subscribers' premises are perhaps 20 miles or more from the exchange. At Port of Spain, Trinidad, there is a central-battery system; it was installed by a company, but they do not find it satisfactory, and they have had to connect the distant suburban and country subscribers to a separate magneto board.

Now if this is the case with a central battery, what chance is there of satisfactorily maintaining an automatic system? Not only are we to expect insulation troubles with the high pressure on the lines, but there are also the somewhat intricate selectors and pre-selectors and other apparatus which would have to work in a climate capable of causing trouble even in a simple magneto system. In Havana, Cuba, an automatic system is working and appar-

[illegible]

[illegible] reached a tropical climate, the damp atmosphere, often [illegible] acting upon the copper at these weak points ate it [illegible] it was the line coils [illegible] suggest that the damp alone [illegible] the fault. The only conclusion we can come to is that simple enamel insulation is not suitable for very fine gauge wires, but for all other purposes it certainly seems to give entire satisfaction. We [illegible] coils, which cannot be said to be the case with either silk, cotton, or wool. These faulty coils are at present being [illegible] then dried in a vacuum and placed, whilst there, in a bath of "Voltalac," so that this insulating varnish may work its way right into the heart of the coil. This, it is hoped, will be successful, but naturally only time can tell. It may possibly be sufficient to treat enamel-insulated coils with this Voltalac, in which case there would still be the advantage of having the coils small. This will be tested shortly. [illegible] that, should any fault occur in it, the complete coil must be scrapped, as unwinding and rewinding on the spot is out of the question. On the other hand, faults in such [illegible]

[illegible]

[illegible] East Africa, European [illegible] Governments have to rely on half[illegible] men, neither of whom, with rare excep[illegible] have mental [illegible] With the only av[illegible] It [illegible] ments long for a simple automatic system.

[illegible] change is the objection that subscribers have to "ringing [illegible]

Fig. 1 shows the arrangement. A small lamp and clearing relay is used, the lamp obtaining current from large [illegible] joined to the battery. When the receiver is off its hook, [illegible] the line, through the subscriber's induction coil, back by the other line and coil to the battery. With these coils, [illegible] the clearing relay armature falls back and completes the lamp circuit. The advantage of this particular arrangement is that there is a very remote chance of the relay armature falling back and causing the lamp to glow, unless the subscriber's circuit is broken, so that the subscriber is not likely to be cut off in the middle of a [illegible]

create a disturbance with the subscriber or cause much inconvenience. In fact, it would only act as a warning to the staff that the line requires attention. Besides, it is unlikely that both lines of two subscribers connected through to each other would have a low insulation resistance, and the fact of the clearing signal being given on one cord only would call the operator's attention to the connection.

LINE.

The normal type of overhead construction now employed in most tropical countries is fairly well standardized. The poles used are either of a type with wrought-iron taper tubes and cast-iron bases, or of the Hamilton type which are built up of tubes of riveted sheet steel.

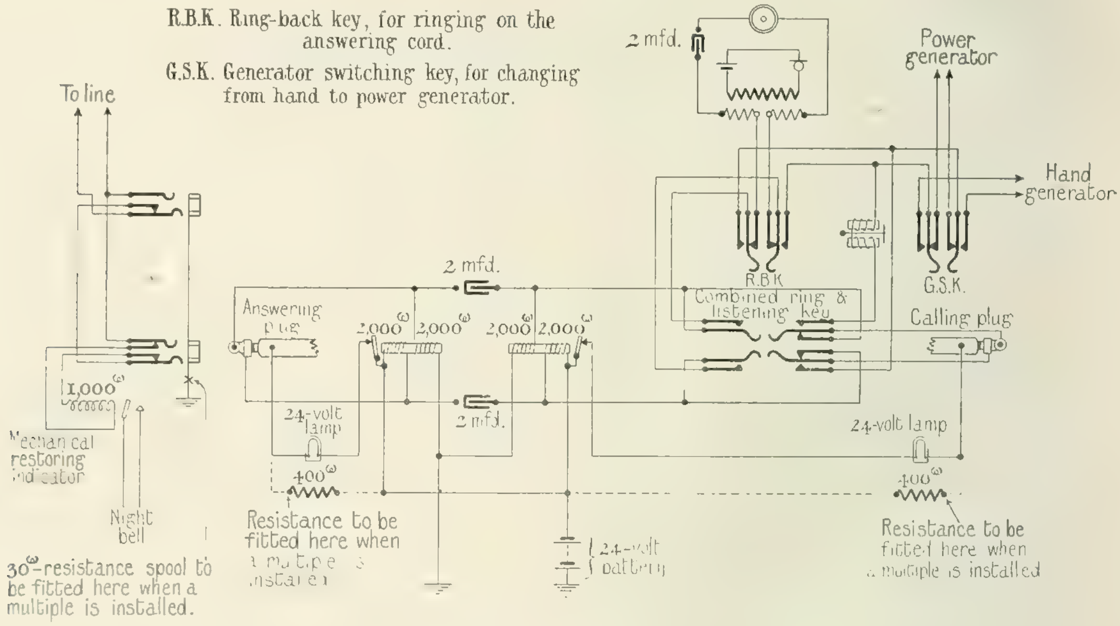


FIG. 1.—Circuits for Magneto System with Generator Calling and provided with Supervisory Lamps in Exchange Cord Circuit.

In most parts it is hopeless to use wood poles, owing to the prevalence of white ants, which in a very few years demolish the whole of the interior of such poles. The arms, on the other hand, are fairly often of this material, for the white ant will not work its way up 15 or more feet of iron tube to reach these arms, and in some countries most excellent hard wood is obtainable locally.

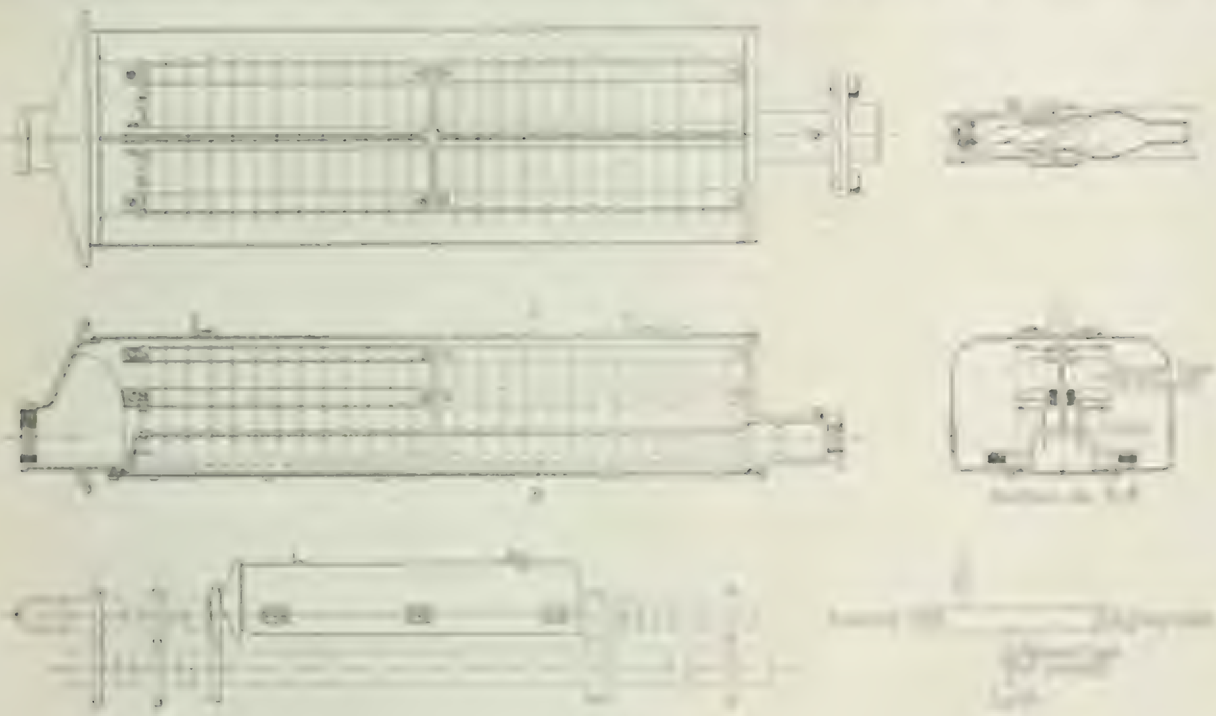
Where hard wood is not obtainable, tubular iron arms are employed. These arms carry 6, 8, or 12 Cordeaux porcelain insulators, mounted on iron stalks. Thus the very best practice is followed, and the lines which the author has seen suffer in no way as regards workmanship and finish when compared with lines in this country. Yet the average insulation of these lines is very low. The atmosphere, with a humidity of 80 or 90 per cent, naturally has considerable effect in reducing the insulation resistance, as is the case here in times of damp fog, when the humidity is about the same as the normal value in the tropics.

A more troublesome factor, however, is the vegetation, more troublesome in that, whilst the clearing away of these trees would be of very great assistance in keeping up the insulation resistance, the high cost of doing this in most places, and the reluctance of the Government and the public to allow this work to be carried out owing to their inability to realize that trees can interfere with the working of a telephone system, hamper the engineer from taking the only real measure which would enable him to reduce very appreciably this fault.

There are usually in the towns and suburbs rows of trees on either side of the roads, gorgeous flowering trees which it would be undoubtedly a pity to cut down or even lop. Here underground cables would obviate the trouble; or in some places where the houses are low it is possible to erect poles between and run wires over them and away from the trees. Outside the towns, however, the roads run through dense jungles or thick plantations of rubber trees or coco-nut palms. Open land is unknown in the tropics, except to some extent in districts of tea plantations; though not always there. The normal clearing for roads is 60 feet, but in practice such a clearance is often not maintained or even made; and with even 60 feet clearings the line must be within 20 feet of the trees at the best, and is actually often less than 10 feet. These trees vary from 20 to 100 feet in height, and the great majority have long branches or big leaves—such as the coco-nut palms or the feathery branches of the bamboo—so that unless a further 50 feet clearance is made on the side of the line away from the road, and properly maintained, contacts and breakages due to falling trees must remain almost a daily experience.

Unfortunately it is not only the expense of clearing which has to be considered; that of keeping down the undergrowth is also a considerable annual charge. On the other hand, to suggest that all lines should be laid

[illegible]



[illegible]

[illegible]

Another line trouble that the tropical engineer is bound [illegible] groups delight in making their homes between the petti[illegible] covered with a spider's nest as to be itself invisible, the base of the nest being on the arm and the apex above the [illegible] on a line which ran through the jungle and had not yet been brought into use. Such insects are, however, found throughout the tropics, which means that constant attention on the part of the linesmen is necessary to prevent the insects getting such a hold on the insulators. It is quite usual to find, formed in a single night, webs glisten-

Telegraph Engineer of British Guiana, first brought to the [illegible] street, one the telephone line with porcelain [illegible] are blocked up with insects and their webs, whilst the [illegible] obtained, considerable improvement in the insulation should result.

[illegible] use of oil insulators on [illegible]

between Derby and St. Pancras was most efficacious, and that they maintained satisfactory insulation even in the worst weather; it is thus possible that if oil insulators of glass which would not attract insects were used in the tropics the results should be equally advantageous. Unfortunately such insulators are not at present obtainable.

Another widespread source of line trouble in the tropics is lightning. In many places thunderstorms are of almost daily occurrence throughout the greater part of the year. In certain towns a single storm will often result in 50 per cent or more of the subscribers' telephone lines being earthed at the pole boxes, this being caused by the strong discharges through the protectors to earth, which carry so much carbon dust across the gap as to place the two carbon blocks in contact; so that practically after every storm a number of linesmen had to be sent to all those boxes to clean the protectors.

This trouble can, however, be cured to a great extent by using the vacuum type of protector, in which the two carbon blocks are inserted in an exhausted glass tube, the opposite surfaces being serrated and fixed about 1/16 inch apart. These protectors are now used to a considerable extent by Mr. Cadman in the Malay States, and are, the author believes, found to be quite satisfactory. Occasionally an extra heavy discharge will burst the tube, but they are very easily replaced. This possibility, however, makes it essential that fuses shall also be inserted, for if a discharge were so heavy as to burst the protector, the line would be no longer protected and a subsequent discharge might damage the cable seriously.

The one disadvantage of these protectors was their size, which involved the use of a very large pole box, even for 25 lines; but a new type of box designed early this year has practically solved this difficulty. This box is shown in Fig. 2. The protectors are arranged in two vertical rows on either side of a long and narrow chamber, which holds the fanned-out conductors of the underground cable and can be filled up with bitumen. Fuses are arranged behind the protectors at the back of the box, and a double sheet-iron cover encloses the whole box. From the top a wrought-iron pipe goes up the pole, carrying the leading-out wires, which latter are invariably twin-conductor lead-covered cables, each twin terminating, in accordance with the British Post Office practice, in two Purves and Sinnot terminal insulators. These insulators, owing to their covered-in and bitumen-filled jointing chambers, are found to give very great satisfaction. Altogether this makes a well-enclosed compact system for these distributing poles, with good lightning protection and satisfactory insulation. It is a general rule not to distribute more than 25 subscribers' lines from one pole. Occasionally, however, when lines are distributed from one pole in two different directions, this pole may serve 50 subscribers' lines, *i.e.* 100 conductors. The pole box in this case is somewhat large, but once it is fixed it is quite satisfactory, and it does not weigh more than 100 lb.

A letter from Mr. Sayers, of the Midland Railway, published in the *Electrician* last October * dealt with the subject of lightning protection, and described a method of guarding a line of wires from lightning by erecting an earthed line along the tops of the poles. This practice has been applied to electric light and power lines for some years, but the author believes that though the suggestion had been made before, Mr. Sayers was the first to test this method on telegraph or telephone lines. An iron wire is stapled to the tops of the poles, and also connected to their earth-wires. At each end it terminates in an earth-plate. This arrangement has been found most effective in guarding the lines from lightning. The author would therefore like to call the attention of all engineers in the tropics to this arrangement, and to suggest that they should try this earthed wire on their telephone lines.

For underground work in the tropics the usual practice is to use armoured lead-covered air-space cables terminating in boxes on distribution poles, and hitherto the engineers have followed the British Post Office practice of making the joints so that dry air can be periodically pumped through. The author is inclined to think that this is a mistake, and that the American solid joint would give much less trouble. If the cable is well sealed with paraffin wax immediately it is opened for jointing, the damp could not enter it unless the lead covering was damaged. If such an accident did happen, the length would have to be replaced. Exactly the same result must, however, occur if the practice is to employ open joints and dry air pumping. Once the damp has the chance of entering a cable in the tropics, no amount of pumping will drive it out completely, and the length must be replaced without much delay. Of course the use of the pump might keep the damaged cable going to some extent for a week or so; but, on the other hand, the accident might very well cause a reduction in the insulation of the whole system, for until the hole is repaired the damp can enter the cable, and damp works through a long length in a very short time. It must be remembered that with native workmen it is not always easy to learn of the accident until some time has passed. Another thing is that with the British Post Office system the various tapped and plugged holes at different points of the underground system, for pumping in air, are all possible inlets for the damp.

Armoured lead-covered cables are normally very free from faults, except those due to damage caused by men working on the roads. There is in Shanghai a curious flying insect which is able to bore holes in which to lay its eggs in the lead covering of overhead cables, but the author knows of no case in a tropical country where an insect has damaged an armoured lead-covered cable, or where the damp has caused faults if the joints are securely protected. In low-lying water-logged soil it has been found desirable to lay the cables in troughs filled with bitumen, but otherwise armoured lead-covered cable gives extremely little trouble.

Staff.

The last trouble peculiar to the tropics to which the author wishes to refer to-night concerns the local staff. It would obviously be far too expensive to obtain from England not only engineers, but inspectors, foremen, and linesmen. For, speaking generally, no white man can live in the tropics—with any pretension to comfort—on less than £250 per annum; and in countries where the men have to pay for their voyages home and back when leave is granted, they should receive about £300 per annum

* *Electrician*, vol. 74, p. 55, 1914.

[illegible] serious responsibility, seeing that the Government control [illegible] the desirability of the Engineer's proposals, nor do they [illegible] of trained assistants, or, often, of grant- [illegible]

[illegible] trying work, though almost invariably underrated, underpaid, and overworked.

As has been already pointed out, this paper deals entirely [illegible] the senior officials. The author therefore hopes that the [illegible] with which they are not usually associated.

DISCUSSION.

[illegible] telephone troubles in the tropics, but I have had [illegible] latitude, corresponding roughly with the littoral of the Mediterranean. In that district very frequent and heavy storms occur, termed pamperos, storms which arise on the pampas to the east of the Andes, sweep right across the country and destroy everything *en route*. Fortunately [illegible] have a front not much exceeding half a mile, and [illegible] they very effectively destroy everything on that [illegible] communication quickly when heavy lines are concerned [illegible] can be dispatched from the depot without delay. Among the minor troubles there is one caused by a bird termed the hornero, *anglice* "baker," which uses the native [illegible] between the wires, the result being that in wet weather [illegible]

[illegible] If the bird attempts to build round these vertical wires [illegible] but from an entirely different reason. It appears that on [illegible] actually suggested that men should be employed to sweep away these webs from the wires. It can be imagined what it would mean to sweep 1,000 miles of line twice a year. [illegible]

Sir John Gavey.

spiders do not propagate as they do on the pampas. I was interested in the author's remarks as to the perforation of lead cables. Some time ago I had to go into this question and I found that the first mention of the subject was by Mr. John Hesketh, the electrical engineer to the Australian Government, in a communication * to the St. Louis Congress in 1904. He there described five species of bugs or beetles which perforated lead cables. I came across certain specimens in Buenos Aires between 1908 and 1910, and I propose to show on the screen a largely magnified illustration of the perforation. The photograph undoubtedly proves that the author's suggestion is correct, viz. that these beetles perforate the lead in order to lay their eggs in the perforation and not for gastronomic purposes. In the second slide the opening where the vertical perforation took place, and the interior longitudinal cavity can be most distinctly seen. The actual specimens from which these photographs were taken are on the table. In my investigations some question arose as to whether termites perforate lead. The two cases that came to my knowledge were doubtful. One case related to a series of gutta-percha cables covered with lead. The lead was not continuous, and the termites evidently entered where the lead covering had not been made good. The second case was also doubtful. The termite was not discovered, and it was considered responsible for the damage merely because the perforation appeared to represent the type of hole that a termite would make. I think in that case the verdict must be that the charge was "not proven." I observe that the author is in favour of solid joints in lead-covered cables, *i.e.* filling the joints with an insulating compound. Opinion is rather divided on that point. In the United States the joints are universally filled with compound. In England we have not done so, nor in South America. My reason for not quite approving of the filling of the joint is that it is almost impossible to get an insulating material to expand and contract in unison with the expansion and contraction of the lead. As soon as a perforation occurs in the joint I am afraid that the moisture will find its way through to the wires by capillary attraction along the narrow interstice between the insulating material and the lead. In connection with staff matters I am glad to say that we do not experience much trouble. We find no difficulty in getting supervisors, and the one trouble that we suffer from in South America is the loquacity of the people. The public will exchange compliments with the operators, such exchange of compliments considerably delaying the putting through of the calls. We are using our best endeavours to induce the people to adopt the Anglo-Saxon taciturnity in dealing with telephones. We have achieved a little success, and I hope we shall get a little more.

Mr. Cook.

Mr. W. W. COOK: The author has chosen a very interesting subject for his paper, but I think we were entitled to look to him for a little more serious treatment of it. Some good, no doubt, will result from discussing the details of construction mentioned in the paper, but I think still better results would have been obtained if he had spent more time in setting out the operating conditions of the apparatus which he is considering. It is very difficult, for instance, to discuss the relative merits of common battery, local battery, and automatic working if we are given no information as to the size of the place under consideration. There are some indications in the paper that the author is chiefly thinking of comparatively small and isolated systems, but if he has to deal with a large installation in the tropics I think he will find the maintenance of his attitude towards the central-battery system as difficult as that of some of the overhead lines mentioned in the paper. It is somewhat surprising to hear an engineer say that he has "set himself strongly against the common-battery system" unless all the lines are put underground. It reminds me of the time, probably some 15 years ago, when it was gravely asserted that the system could not be applied to London on account of the number of overhead lines. Almost any kind of system will give some sort of service on a small scale, but I think the system to which the author pins his faith is quite unsound. No satisfactory service can be given in a place of any importance when the insulation of the lines is so low that the standard common-battery circuits cannot be used, and nothing but harm can result by shutting one's eyes to the real facts. Another aspect of the paper on which I think the author lays himself open to criticism is on the traffic side. There are very brief references to traffic but they are rather significant. On page 547 he says that some opinion as to the operators' ability can be formed from the fact that they can only attend to from 60 to 80 lines. He gives no information as to the calling rate at all, and therefore we cannot draw any real conclusions. In two cases that came under my notice recently the calling rates were 10 and 2½ per line per day respectively. An equal number of subscribers in those cases would have given loads in the ratio of 4 to 1. Perhaps the author can give us the number of unit calls answered in an hour, and also some idea of the unit call adopted. At the top of page 548 he does not seem to mind whether the operator receives one supervisory signal or two, and I noticed that in explaining the diagram he referred to those supervisory signals as clearing signals. Of course that is only one of their functions. The author is not quite correct in stating that Mahommedan women cannot act as operators, and I have a slide here showing some Mahommedan women operators at work. I have also seen some very good half-caste operators, and I do not think it pays to be pessimistic on the question of native labour. A great deal can be done by training. With regard to line construction, in the centres of large towns underground work of course pays, and generally in undeveloped places the low excavation and reinstatement costs enable us to place cables underground with a smaller number of conductors than would be justified otherwise. The same reasons that lead to the adoption of conduits in this country seem to apply equally well in other places and I should have thought that there would have been very few cases in which armoured cable laid direct in the ground would have proved economical. I was rather glad to see the author's remarks about the filled joint. I am sorry to differ from Sir John Gavey, but I consider that a great deal of money has often been wasted by pumping through cables to clear faults which would not have occurred if the joints had been filled. There is very little mention in the paper about overhead cables—a class of construc-

* G. HESKETH. A new danger to lead-covered aerial telephone cables. *Transactions of the International Electrical Congress at St. Louis*, vol. 3, p. 458, 1904.

[illegible]

before the Meteorological Society. For Scarborough the [illegible] (in January) and the minimum 78 per cent. On the face [illegible] in the morning. Some very interesting records for [illegible] throughout the day, and the mean results for a [illegible] tures can hold (and consequently can deposit for an equal drop of temperature), and partly to the steady persistence of these conditions.

[illegible] that nothing has been done since that time, especially [illegible]

[illegible] acid for 48 hours, and in [illegible] purposes that a telephone engineer can expect it to [illegible] the conditions, but the Post Office specification does not [illegible] oil, a defect which would probably be intensified in the tropics. With reference to the question of construction, I [illegible] aerial cable, especially [illegible] would be the ideal arrangement. [illegible] a service as the underground cable would give to the near subscriber. As far as the insulators are concerned, we have been experimenting in the Post Office with [illegible] glass insulator as good as porcelain, and be[illegible]

Mr. Slingo. breakable insulator, its base being of asbestos. We are beginning to make them in this country now for the reason that I have just stated. It has non-hygroscopic and good insulating properties, and it cannot be broken by a stone or a bullet. The Post Office experience with oil insulators has not been satisfactory. Some were tried on a line in an exposed position on the north-east coast of Scotland where the oil was blown out during high winds. It is possible that the design of the insulator was at fault. If the author of the paper makes any further experiments in this direction I would suggest that he try a heavy green oil such as is used for creosoting wood, but free from phenols and acids. This oil is a powerful antiseptic and would assist in overcoming the insect difficulty. Another suggestion I would make for extreme conditions is to serve the line wire where it is bound to the insulator with adhesive insulating tape, painted with weatherproof insulating paint, the served wire being bound in with insulated wire. Probably a more effective method would be to insert say two or three feet of weatherproof insulated wire at this point and connect up the bare wire at each end by means of copper jointing sleeves. In some parts of South America it has been found necessary to use continuously-insulated wire throughout in order to overcome the trouble due to spiders' webs. In the matter of lightning protection, even with our comparatively tame English thunderstorms, it has been found essential that the arresters should be placed as near as possible to the point of entry of wires into a building, and this practice is insisted on in the Post Office regulations. The choking-back effect of a length of internal wiring between the arrester and the telegraph or telephone instrument is a valuable aid to the efficient action of the protector. The auxiliary protection of a fuse in the line circuit, which the author mentions near the end of his paper, no doubt reduces danger in the case of a protracted thunderstorm, where the wire is subjected to repeated lightning strokes, but it must not be forgotten that the discharge which actually blows the fuse has in every case found its way to earth somewhere on the internal side, and has damaged the cabling or the instrument, and carried with it the potentialities of conflagration. For this reason I cannot accept a fuse as in any sense a substitute for a lightning protector, and, where danger is considerable, I think it is the best practice to build up the efficiency of the protector proper by making it include two or more spark-gaps separated by small and strongly insulated inductance coils which serve, as one may say, to chop up the high-voltage waves, and greatly increase the probability that they will be caught by one or other of the spark-gaps at or near a point of maximum intensity. I should like to ask whether the author has tried protectors of the hermetically sealed copper-tube type, as they are not so liable to break down as the type in general use. It would be well to fit them in a box on the next pole to the leading-in pole, the protectors being connected to the lines by strongly insulated leads. It is of great importance that the wires used for leading-in or for connecting paper-core cables to aerial lines should be insulated with a good dielectric. The insulation of the wires now used for this purpose by the Post Office will stand a pressure of over 5,000 volts. The strong dielectric helps to absorb the energy of the lightning discharge. In this connection the experience of the Newcastle-upon-Tyne Electric Supply Co.'s system of aerial high-tension work (see discussion on Mr. Welbourn's paper above referred to) is instructive. There is one other point which I should like to mention. An automatic exchange has been erected at Simla, and before it was completed an order was given for an extension. The following is an extract from an official report upon that exchange in the year 1913–14. "An automatic telephone exchange with 700 lines was successfully installed at Simla and has proved very popular, the public finding it more rapid, efficient, and reliable than the old system." That is, I think, a very good testimony. I am very glad that this subject has been introduced, and I hope that this is the first of a number of papers dealing with it, because I am sure that the ventilation of a problem like this must be to the benefit of all telephone engineers.

Mr. Kingsbury. Mr. J. E. KINGSBURY: I should like to repeat the remarks of Mr. Slingo in regard to the great advantage of a paper of this practical nature which gives the manufacturer at home some direct information regarding the climatic and other conditions which his apparatus has to meet. So far as telephone apparatus is concerned, we were given some of the results of tropical experience at quite an early stage. I recall that the magneto as manufactured for European use was modified as the result of tropical experience. Some of the early American magnetos which then contained a number of iron castings were sent to somewhere in the East. Fortunately a representative of the manufacturer was on the ground and saw them unpacked; the result was that any part of the instrument that could be made of brass or anything but iron was so made thereafter. Some friends in the tropics wanted us to make the magnets of brass also! I am sorry to hear the results that have been obtained with enamelled wire, because I was in hopes that enamelling had got over one of the difficulties which had been found with so many other substances. Insects are not only troublesome in insulators. We had trouble with a multiple switchboard cable and the cause could not be discovered for quite a long time. Eventually it was found that moths had made their home in the wool covering of the wires. I was in hopes that enamelling would enable that trouble to be overcome, and from what the author tells us I am still in hopes that it will do so in the case of the comparatively large wire of which the cable is composed, although it does not appear to be free from trouble in the smaller wire. On the subject of cable joints I am in somewhat of a dilemma, for I must disagree with either the author or Sir John Gavey. It will have to be with Sir John Gavey, for I confess that the author's remarks on the subject of solid joints seem to me to have a substantial foundation. The air drying-out system is rather a luxury. I can quite conceive that it may be very much better to have a solid joint, because it has been clearly proved that that is where protection is required. It must be remembered that the solid joint is practically one of the links in the development of the completely dry-core cable. Previously the cable was filled throughout its entire length. It was then decided after very careful consideration that the point of danger in a lead-covered cable was at the joint, and in a draw-in system the cable was not subjected to any trouble except at that point. It may be assumed that in

[illegible]

[illegible] by any means record all that took place in this country [illegible] insulation trouble. This in tropical countries is not due [illegible] humidity, and it may be taken that it is the most felt in those [illegible] of the sort that the author has referred to have not been experienced. In those trying conditions many features of home-engineering practice are quite unsuitable. Red [illegible] Preece, Cardew, & Snell that uralite is so hygroscopic [illegible] however, do not apply by any means to all countries [illegible] countries this point should be borne in mind. Altitude makes all the difference. It is quite a common thing to

[illegible] continuously under pressure. A previous speaker has criticized the system outlined in the diagram, and more than one speaker has reflected on the author's expressed [illegible] opinion is that the insulation troubles under a [illegible] has gone so far beyond the plain magneto as to give a [illegible] under the existing distribution conditions, which, owing to the low subscriber density, consists to a larger extent, of open wires. Another speaker has referred to Simla, where [illegible]

Mr. Weightman.

possible. This would specially apply to any automatic system. The author has dealt very fully with enamelled-wire troubles, but I am inclined to think these troubles are not confined to the tropics, although they are bound to be felt more there owing to the damp penetrating the windings of coils. I have heard it said by two manufacturers that in the process of enamelling it is impossible to give the wire a uniformly thick coating of enamel. The smaller the gauge of wire the greater liability there is for the coating to vary, and in the finer gauges the covering may be a mere film in places, and there may even be, here and there, minute spots without any covering at all. The author's experience shows that there is a risk of insulation weakness in enamelled wire, and there is room for further investigation of the matter by manufacturers. Practically all enamelled wire used for coil windings is made to Post Office specification. Among other tests this provides for a 10 in. sample piece of wire being stretched to 10 per cent of its length, after an hour's immersion in water, and while so stretched it is again immersed in water and subjected to a pressure of 10 volts, and the enamel must stand this without breaking down electrically. I am inclined to think this test is not severe enough to bring to light the minute imperfections I have referred to, and which appear to be the cause of the trouble referred to by the author. I suggest that the length for test be much increased, that it be stretched in a bath of mercury instead of water, and that the pressure be increased to 50 volts. The larger gauges of wire used on coils would no doubt stand this, but a gauge would I think be reached at which the insulation would break down, and no enamelled wire so small as this critical gauge, whatever it may be determined to be, should be used, on tropical equipment at any rate. Where high-resistance windings are required, larger bobbins wound with larger wire should be used. The author has referred to the white ant and other insect pests in tropical countries. The natural abode of white ants is in the earth, but they travel considerable distances through tunnels of their own making, and they have a wonderful way of sensing the position of things they are fond of. They have a marked partiality for most kinds of wood, and that is one of the main reasons why it is almost impossible to use wood poles in most tropical countries. The ants work in the dark and in silent situations. They are most destructive of woodwork in buildings, which they usually enter through weak points in the foundations, but they are easily kept at bay if the foundations and the walls for two or three feet above the ground are built with cement. I have never seen a telephone attacked by them. The mere ringing of the telephone bell would disturb them, and once disturbed they, as a rule, quickly run back in their tracks, which they close up behind them, and make for quieter places. Glass insulators would probably be a cure for spiders but not for all insects. Hornets, for instance, build anywhere about the arms and insulators. But if the insect trouble were mitigated by the use of glass insulators, I am afraid the standard of insulation would suffer. In Canada where the climate is very dry glass insulators are the standard, but on long-distance lines, and in damp localities porcelain insulators are used to keep the insulation up to as high a standard as possible. It would not be a costly experiment to try glass insulators

POST OFFICE TELEGRAPHS, NATAL.

LINE INSPECTION REPORT.

The District Engineer.................................

I have to inform you that Lineman........................left this office at......m. on the............19..., to inspect the..................Section of the ....line, and that he returned at......m. on the...............19...

I have put to him the questions printed below. The answers recorded are his and they appear to be given in good faith.

....

..................................19...   Signature.............................

QUESTIONS.	ANSWERS.
1. Has he examined all poles on the line? If so, how many did he find loose?	
(*a*) Did he earth up and re-ram the latter?	
2. In his examination of the poles did he find any bases cracked at the top? If so, how many, and how many collars are required, and for what sizes of bases?	
3. Has he cleared the line of bush, and branches of trees, and undergrowth?	
(*a*) Has he maintained all clearances through trees at their original width?	
(*b*) Have any new plantations of wattle or other trees been started on the line? If so, where and of what extent are they?	
(*c*) Are there any fruit or ornamental trees on the line, and are these likely to come into contact with the wires in windy weather? (It should be understood that a Native Lineman must not *cut down* trees on private lands, or interfere in any way with fruit or ornamental trees.)	
4. Has he cleared all cobwebs, hornets' nests, kite tails, etc., from the line?	
5. Has he cleared the insides of all insulators he found dirty? If so, how many?	
6. Has he examined all stays, and are all in good and tight condition? How many has he tightened?	
7. Has he examined all tapes, binders, and binding wires, and are all in order? How many of each has he renewed?	
8. Has he replaced all defective insulators? If so, how many?	
9. Has he fitted any insulators with new india-rubber washers? If so, how many?	
10. Has he tightened all nuts of spindles, arms, etc., and are these nuts secured with iron binding wire twisted round the bolt hard up against the nut?	
11. Are all arms in good condition? Have any been replaced? If so, how many?	
12. Has he tarred or painted any poles, stays or arms? If so, how many of each?	
(*a*) Did he remove all traces of rust before applying the tar on the poles and stays?	
(*b*) Did he exercise care to avoid bedaubing the insulators and wires with tar?	
13. Are all lightning rods tightly fixed, and in upright position?	
14. Are there any spare materials on the line? If so, of what kinds and where situated?	

GENERAL REMARKS.

....

....

....

N.B.—All sections of line, with the exception of those inspected quarterly by Electric Train Staff Linemen, should be inspected by a Native Lineman once a month, and a report furnished to the District Engineer, by the Officer responsible, on this form by first post after the performance of the inspection.

[illegible] was brought into use on which the controlling officer had to write the native's replies to a number of set questions as to the work he had actually done. With the introduction [illegible] much better work was got from the native linemen. [illegible] European linemen, who again were supervised by engineers, and the system of telegraphs and telephones which connected almost every town and hamlet in the colony was maintained in a thoroughly efficient state.

Mr. E. A. Laidlaw: Telephone subjects are very rarely discussed before the Institution. I am certain I shall be voicing the opinions of the telephone engineers that more papers on this subject are required. In the paper the author mentions practically two-thirds of the globe, and I should like to ask him whether he considers that the equipment and apparatus should be uniform for all those places or whether special apparatus should be designed and fitted in those climates where there is a very humid atmosphere. As an instance, the climate of Nairobi is very hot and dry, but in the Malay States it is very hot and damp. Uniform apparatus might perhaps be an advantage, but the question of cost must come into the matter, as apparatus designed and made for very hot and damp climates would probably cost more than that used in this country with satisfaction. It would appear, therefore, that it would only be necessary to have special apparatus for very humid atmospheres. I notice that the author recommends that teak should be used for subscribers' instruments. I am of opinion that teak is possibly the very best wood to be used in the tropics. It is much better for wall instruments than metal, as from an opinion expressed by engineers from the tropics all metal wall instruments, however well enamelled, soon deteriorate and look very shabby. The enamel cracks and rust appears on a great part of the metal. This fault does not appear on desk type of instruments as these instruments are not usually fitted on or near a wall. Teak, however, is not quite as handsome to look at as walnut but is a good practical wood. With regard to the system, I should like to agree with everyone on this matter, but as I cannot, I should like to disagree with the view implied by Mr. Cook that countries with a humid atmosphere, partly untrained staff, long lines some 25 miles long, open wires running through trees, should be fitted with a common-battery system. With a magneto system lines could be worked and give a fair service even though the insulation is not perfect, whereas if the common-battery system were [illegible] ance beyond the [illegible] Another interesting [illegible] enamelled wire for relay coils. The [illegible] gets from the author's paper is that the use [illegible] wire for relay coils is wrong. I think he has [illegible] enamelled wire has not come up to expectati[illegible] wires. The fault which he ment[illegible] the wire, has been found in this [illegible] due to coils becoming disconnected have been found in [illegible] Glasgow, and I believe that the Post Office are still experiencing trouble through coils becoming disconnected due [illegible] not been given in the past [illegible] the trouble and what really has [illegible]n. It would appear that in districts whe[illegible] winding, and the coil is subjected to a [illegible] electrolysis is set up and the wire becomes c[illegible] finally disconnected. The author's suggestion [illegible] cally sealing up the coil and keeping the [illegible] appears a good one and in humi[illegible]uld I believe, overcome any trouble. I [illegible] interested to hear the results that the author obtains from the experiments which [illegible]

Mr. A. J. [illegible] author was prepared to endorse the dictum of a critic of [illegible] leagues to-day. I really cannot believe that the English [illegible] getting a correct indication of the trouble complained of. With a very long experience of the design of apparatus and of telegraph plant I have always been impressed with this point. Time after time somebody has said, "Oh, we are always having trouble with this; cannot something be done for us?" On replying, "Why do you not report it?" we are told, "I could not see how to get over the trouble." I always answer, "If you report the trouble it is for the 'consulting' engineer to find the solution." I suggest to the author that he should impress this upon the engineers in the tropics. Let them send samples of the trouble, with the clearest explanation that they can offer, and I think it may safely be promised that the English telegraph engineer will go a long way towards [illegible] graph engineer can produce any very great effect upon the [illegible] suggest will prevent a herd of elephants from rubbing up

Stubbs. against a bamboo pole to the disturbance of its alignment; but even in such matters as that, one has known where smaller cattle have been kept away from the poles by the simple device of putting a pile of loose ballast around each of the poles. In regard to the common-battery system, subject to correction by those who have a wider experience of America than I have, I believe that it is something in the nature of standard practice in the United States not to connect these very long circuits, but to locate them on a special magneto switchboard. This appears to be the plan adopted at Port of Spain, to which the author takes exception. It may strengthen the author's position to know that the British Post Office has already adopted the American plan of boiling-out the joints of paper-core cables with hot paraffin wax, and that the screw nozzle attachment is recognized as obsolete practice.

Alpine. Mr. G. McAlpine: I am afraid that the author has so thoroughly covered the subject of telephone faults in the tropics that there is nothing left for me to add from my own experience, but perhaps I may amplify those which he has enumerated. There is one class of line construction which the author has not referred to, namely, lines which follow tropical coasts. There the disadvantages to which he refers are particularly exaggerated. On a sea-coast in the tropics which is subject to monsoons all the year round, the lines, insulators, poles, and everything else are practically encrusted with damp salt throughout a large portion of the year. Obviously it is impossible to use iron poles in such circumstances, and wood must be employed. Teak is found to be the only useful wood. Iron wires likewise are impossible; and we are obliged to use copper. Light copper wires of, say, 100-lb. section are not advisable from the economic point of view inasmuch as they corrode away in less than 10 years. As a consequence one is forced to adopt the expensive method of using somewhere about 400-lb. copper wire for all lines erected in such localities. In several colonies copper-clad steel wire has been tried, but I am sorry to say that it has been found to have a life of less than three months. All sorts of methods have to be tried to remove the salt and maintain the insulation of the circuit. Frequent washing has proved to be the best out of many methods. Washing followed by oiling, although it seemed successful, in the end made the difficulty worse. As a contrast to that particular class of line in the tropics one sometimes comes across the other extreme. The climate may be particularly good, the atmosphere clear and dry, but then one is confronted with the difficulty of the geography of the country itself. In rolling, hilly country, such as one finds in the tea-growing districts, it is impossible to maintain more than about eight or ten poles to a mile owing to the irregular contour of the country. That introduces the problem of the tensile strength of the wire. Luckily in such localities the wind pressure does not reach high values, so that in spite of the ridiculously small number of eight poles per mile there are many hundreds of such lines working satisfactorily. The best average conductor in such cases has been found to be of 150-lb. silicon bronze. In the case of telephone wires, owing to the long span, a spacing of 24 inches in a vertical plane has been found to give the best results. As regards the poles for use in such a locality, it is obvious that the factor of transportation is the dominant one. The weight must be kept small, because everything has to be carried on coolies' backs. Therefore Hamilton steel poles or something of the sectional type become essential. Another class of route affecting the pole question is where the line is parallel to the railway. In such cases one may generally obtain discarded railway rails; hence a problem found in all tropical countries is the manufacture of poles out of railway rails, generally of about 72 lb. section. When made locally such poles are found to be cheaper than any imported type. The average life of telephone instruments as used in many tropical colonies is not more than five years. Enamelled sheet iron which is used in some designs of telephone instruments is absolutely non-permissible; it is corroded through by rust in a few months. One difficulty, which tends to conservatism and which I do not think I have seen mentioned elsewhere, as regards the introduction of new and modern types of instruments in tropical countries, is found in the character of the natives. Petty jealousy runs so high between the native shopkeeping classes that if a new improved type of telephone instrument is installed for one subscriber, unheard-of faults develop in a most mysterious way in the telephones of the neighbouring subscribers. This goes on until at last the instruments have to be taken away and replaced by the more modern or prettier type. That is not merely a whimsical experience; it is exceedingly widespread and serious because there is no cure for it. It is impossible to prove that the faults are due to mischief; one has simply to take them as they come, and in the end it offers a very serious obstacle to the introduction of new types. Previous speakers have referred to enamelled wire. Personally I have tried every variety of enamelled wire that I could get in the tropics, not for the rather trying conditions imposed by use in coils but merely to test the wire as such. It was used for wiring purposes underneath instrument tables; but under such good conditions, where the greatest potential never exceeds 50 volts, the wire in every case broke down in about three months. In conclusion, I think the thanks of every colonial telegraph or telephone engineer are due to the author for having brought forward the very serious difficulties of an administrative character which hamper this branch of engineering—especially in the smaller colonies. Not only is the engineer in danger of becoming a mere "red tape worm," but he is compelled to work under an organization, generally of a territorial order, which is by no means suited to his requirements. The merits of functional organization cannot very well be appreciated by the non-technical heads of postal departments. It is this administrative trouble which is the explanation of the very inadequate salaries paid to colonial telegraph engineers; whose remuneration is governed, not by their responsibilities, but by the salaries paid to postal and clerical officials.

Mr. Webb. Mr. H. Laws Webb: I agree with Mr. Cook that a good many details are omitted from the paper. Perhaps the author will give us some of them in his reply. I refer particularly to such subjects as development, the number of subscribers to be served, and rates. It is idle to discuss the kind of central-office equipment proposed to be used if we do not know the number of subscribers, the density of subscribers in the area, and the probable growth. I think information as regards those points would add to the value of the paper. The difficulties referred to in the paper may be classified generally under three headings:

[illegible] with, and it is impossible to say arbitrarily that the central battery will not do, or that magneto is the proper apparatus if one does not know the size and development of the area which one is considering. As to operators, that is another point where it is mainly a question of administration. One [illegible] equipped training school, and a competent and efficient chief operator or matron to train them. If one has, one can do wonders with very unpromising material. As [illegible] Mahommedan girls do actually work as telephone operators. In Constantinople we were rather surprised to find that Mahommedan girls would become operators. We expected to recruit the staff entirely from the Christian and Jewish communities, but as a matter of fact Mahommedans did offer their services and proved competent operators under proper training. As regards glass insulators, I have no doubt the author knows that glass insulators are used very commonly in the United States, where, although the conditions are naturally not so severe as they often are in tropical countries, they are at certain times of the year very severe. Reference is made in the paper to armoured lead-covered cable laid solid, which is of course not good practice in a place where there is likely to be development, or where the cable might have to be withdrawn and larger sizes substituted. If it is likely to be a fixture such construction is often convenient and cheap.

Nash. Mr. G. H. NASH: After reading the paper I sent for my Company's files dealing with this question and found them to be approximately 4 inches thick and teeming with information regarding the protection of tropical apparatus; therefore, in a sense, I desire to offer a protest that such an important subject should be dealt with at only one meeting, because discussion sufficient for many has necessarily to be crowded into one. Many of the points that I [illegible] their apparatus. An example may perhaps illustrate my point more clearly, and for this I will take a subscriber's instrument. How should the woodwork be finished [illegible] making wood joints; if so, should they be of brass, copper, or iron? Are wood joints allowable; if so, what kind of glue should be used, ordinary or marine? Information is sought regarding the insulating properties of the set, both [illegible] insulation obtainable between the assembled metal parts [illegible] to be deposited between the springs, thereby lowering their insulation? What material should be used for separating the springs, ebonite or mica? Is it desirable to ventilate the set? I believe that the foregoing will have indicated a few of the points which arise in one's mind in connection with the instrument alone. These and [illegible] arise when referring to [illegible] facturer who has to make apparatus for the tropics has a considerable amount of difficulty to contend with and he should, therefore, receive as much information as possible regarding the experience that has been obtained by those [illegible] necessarily look for help. In conclusion, I should like to ask our colleagues who reside in the tropics to make a rule of giving full details in connection with any trouble when writing home complaining about it. It has been my experience that such details are frequently lacking, with the result that we are inclined to believe that the failures are more often due to the use of native employees, who are [illegible] to overlook possibly the effect which [illegible] may be actually producing.

[illegible] remarks in support of what Mr. Weightman has said with regard to tropical conditions. The climate on the coast may be very damp and hot and the humidity very con[illegible] more particularly in the rainy season, during which period

most of the instruments and overhead wires have insufficient insulation resistance, but in the inner part of the country and in the highlands the climate will be dry and any sort of telephone system will work well. I have noticed the difference in the plains of India, in Ceylon, and also in the interior of Brazil. Then with regard to the instrument itself, I think for tropical use it requires a little more attention than it usually receives. The microphone should always be damp-proof. In many instances I have noticed that cheap telephones are used, and their water-proof qualities are left entirely out of sight. With regard to the telephone receiver, in a damp climate the diaphragm is very likely to get coated with moisture during the night and early morning, so that the vibrations of the diaphragm are damped and speech becomes indistinct. I think that manufacturers should pay more attention to the preparation of the diaphragm. The upkeep of the instrument deserves the careful consideration of all telephone engineers. I am very glad that the question of the insulation of overhead wires in connection with the common-battery system has been mentioned. For good work the cable system should be complete up to the subscriber's instrument, whether the cables are underground or overhead. The aerial cable is eminently suitable for moderately long distances, and is probably almost as cheap as an overhead open-wire system at the present time. The author has suggested the use of glass insulators with an oil rim for overhead wires instead of the ordinary Post Office pattern of porcelain insulators. We have tried the porcelain insulator with the oil rim on long lines in India, and we have found that the oil soon gets covered with a coating of dust; its properties then fail. In the end the insulator is no better than the plain porcelain double-cup insulator at present used. I am glad the author has borne testimony to the arduous work and the constant vigilance necessary on the part of all engineers in the tropics, because I am sure they do not always get the praise and credit that they deserve for all the trouble they take.

Mr. Harrison. Mr. H. H. HARRISON: For some time our practice with tropical instruments has been to use teak for the wood and to sub-divide the interior winding, running it in chases filled with compound or wax. With regard to the poor insulation of open lines mentioned by the author, I should like to ask whether he has used the so-called indestructible cable invented by Hackethal. The author has referred to the automatic system in use in Havana, Cuba. I cannot say how far the climate at Havana compares with that of some of the tropical places which he mentions, but I know that from the telephone engineer's point of view it is troublesome. I have brought a chart with me (Fig. A herewith) which illustrates the phenomenal telephone growth in Havana since the installation of the automatic system. With regard to the question of enamelled wire, we were animated by the same hopes as everybody else when we first took up its manufacture and applied it to the coils of telephone instruments and other apparatus which we make. I may say that in the initial stages of manufacture there was a decided difficulty in getting anything like a uniform coating on the smaller sizes of wire, but we are getting over that difficulty now. It is, perhaps, hardly necessary to tell the author that there have been considerable improvements in the manufacture of enamelled wire during the last two years, at the beginning of which period I presume this paper was in contemplation. Our practice at the present time with telephone and telegraph instrument coils is to use enamelled wire, silk-covered and impregnated, and that has given very good results. We have received no complaints since that method was adopted. With regard to the author's suggestion as to impregnating

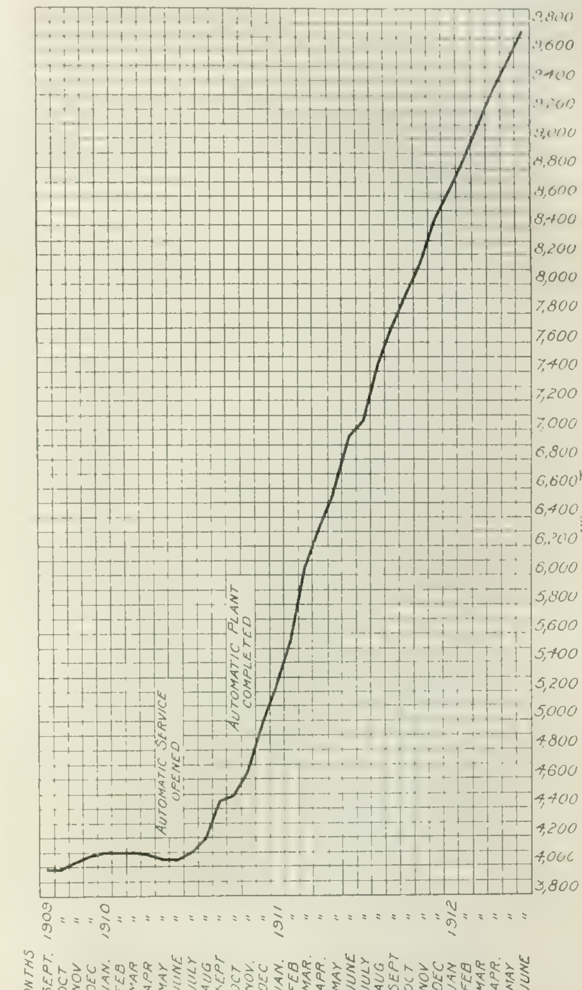


FIG. A.—Curve showing the Growth in the Number of Telephones connected to the System of the Cuban Telephone Company.

coils wound with enamelled wire, it would probably be better for him to consult the manufacturers of such wire, as the impregnation might not suit the particular composition that the manufacturer of the wire adopts. The author's reference to Mr. Sayers' practice on the Midland Railway in connection with quadruplex circuits is very interesting. The working margin with respect to leaky circuits is very much greater in the case of a double-current duplex circuit than with a single-current duplex circuit. In the quadruplex we have double-current and single-current duplex working combined, and, consequently, quite apart from the split-signal difficulty on the "B" side, there is also the inherent difficulty, due to leakage, on this

[illegible]

trouble, and I do not think they should be employed since [illegible] instrument which had ebonite insulation. It had only been in use for two years and every insulated nut and screw was loose. Another drawback to the use of ebonite is its [illegible] for disconnection. I should very strongly advise the use [illegible] experience has been with this class of instrument. In the case of receivers for the tropics I should not only suggest a metal case but also a metal cap; the cap need not be rounded for the ear as I find flat ones are quite comfort- [illegible] In places where it is not possible to [illegible] transmitter will give the better transmission, and if the [illegible]

[illegible] pole so that the [illegible] lutely efficient.

[illegible] indebted to the author for this paper, for they will now know better the conditions prevailing in the tropics and [illegible] I shall be glad to hear if these [illegible] able. The author mentions that he is entirely [illegible] a reasonable insulation on the lines, and (b) the fact that some of the lines are about 20 miles long. With reference [illegible] insulation could not be [illegible]

system (the latter being suitable for working on lines that are adequate for the former). The author quotes instances of both common-battery and automatic exchanges in tropical climates, and according to most reports these are reasonably satisfactory. The author also objects to automatic systems because of the intricate selectors and other electro-mechanical step-by-step mechanisms; doubtless, trouble might be experienced with these when a film of moisture covers them, but such apparatus are not essential features of an automatic system. The Relay Automatic Telephone Company have developed a system using relays entirely, and it is acknowledged by the author that relays have proved perfectly satisfactory for use under tropical conditions. Relays, which require little adjustment, are suitable for enclosing in small units with covers that practically enclose them in a sealed chamber and should, in my opinion, give every satisfaction. Automatic relay switchboards are suitable for small or large exchanges and should be economical in first cost and maintenance. The author gives very little information regarding sizes of installations required and traffic conditions, and I should be pleased if he would specify what sizes of boards are usually required, that is, the present equipment and probable ultimate capacity, and also the approximate number of calls per line. It would be interesting also to know whether these are generally used entirely for local work, or whether there is a considerable amount of inter-exchange and long-distance work.

Mr. Noble. Mr. W. Noble (*communicated*): Given a material which will successfully resist or prevent the attacks of insects, there should be no difficulty in preventing them from obtaining access to a telephone case. Such a material is evidently available in teak, and I see no reason why mild-steel cases thoroughly enamelled should not be satisfactory. In a well-made telephone of good design it would be easy to place a brass plate which would move with the switch-hook and would yet fit so well as practically to close the instrument. As regards the terminals, it is common practice to place them inside the instruments. It is now a number of years since the Post Office ceased to buy the old type of ebonite receiver case. The trouble was not that the sheath became soft and pliable; but when the receiver was accidentally knocked off the telephone hook or off the subscriber's desk it was broken so frequently that the Post Office came to the conclusion that an alteration in design was necessary. A brass case was adopted to give the necessary strength, and this case was covered with a closely fitting ebonite sheath slipped over the brass and held in position by a screwed end cap. This produced a very good receiver body, but in the effort to reduce the cost of construction a trial was then made of a brass case coated with enamel. The result was unsatisfactory, but one of the objections to the use of an enamelled brass case in this country will not apply to the tropics. I refer to the fact that in very cold weather the use of an enamelled receiver case has a very chilling effect upon the fingers. The main objection is that the enamel soon wears off that portion of the receiver shank which comes in contact with the hook in which the receiver rests when not in use. We had many receivers brought into use in busy Public Call Offices and they, after a short period, acquired a decidedly brassy hue. Other materials for coating receiver bodies were tried, among them a substance known as "Pellolit" which gave results much superior to enamel. It was found, however, that extension of the number of ebonite working firms had considerably reduced the cost of coating metal articles, and ebonite "cured" on to the brass case of the receiver has for some years been the Post Office standard practice. We have a testing machine which automatically lifts a receiver three or four inches and throws it on to an ordinary receiver switch-hook every two seconds, and thereby we have made comparisons of the resistance to wear of various materials in conditions very analogous to those obtaining in practical use. We found that whereas most grades of enamel wore through to the brass in four or five thousand throws, Pellolit, about 25 mils thick, stood about 60,000 throws, whilst ebonite coatings of the same thickness have been subjected to as many as 300,000 throws and yet shown hardly any sign of wear. One or other of the foregoing methods may provide a solution of the difficulties which the author has experienced with ebonite receiver cases in the tropics. With regard to lightning protectors, these should of course be fixed on the stonework of the building near the point where the line enters. The protector lead should be connected direct to a good earth. Much of the trouble in the tropics is due to bad earth, and where a test proves that the earth at the building is not good a wire should be run back until a low-resistance earth is found. The author is opposed to the use of the common-battery and automatic systems in the tropics and expresses himself strongly in favour of the magneto system. His objection to the former systems seems to be based upon:—(*a*) Insulation difficulties if the system is aerial with open lines; (*b*) high cost if the system is underground with long subscribers' lines. If either of these objections were removed presumably the author would not favour the magneto system so strongly. Now it seems to me that a compromise would remove the difficulty. In a town most of the subscribers are located within the town boundary and their lines are comparatively short. Why should not these subscribers be served by underground cables, whilst those whose lines are too long for economical underground service could be reached by means of open wires. If the exchange were of the common-battery type a large percentage of the subscribers' lines could be equipped and worked on ordinary common-battery principles, while those subscribers whose lines were such that the insulation was likely to fall below a certain figure or are outside the limit for common-battery working could be dealt with on a magneto signalling basis. These long lines could have their answering jacks concentrated at a definite part of the switchboard, but it would not be necessary to place them on a separate board or to remove them from the multiple. As regards the employment of automatic equipment in tropical countries, such equipment would require to be designed and constructed by engineers thoroughly conversant with tropical requirements. But automatic equipment of the types now on the market would not remove the staff difficulty entirely. It must be remembered that, although operators are displaced, the apparatus that takes their place requires attention of a highly skilled character, and the requirement of an increased technical staff may cause an administration as much as, if not more, trouble than the provision of an operating staff. In dealing with the question of operators, the author states that only 60 lines per

[illegible]

[illegible]	[illegible]
Minimum " " " "	56
[illegible]	[illegible]

Difficulties or worries due to the failure of subscribers to [illegible] a large percentage of [illegible] [illegible] of opinion that colonial posts for telegraph and telephone engineers are not sufficiently attractive to induce able officers to apply for the appointments. The prospects in the Home Service are now so good that senior officers of wide experience will not go to the tropics for the salaries offered. An experienced telegraph engineer will not go to [illegible] even though given the high sounding title of "Assistant Postmaster General and Telegraph Engineer." The author near the close of his paper says, ". . . Happily for these tropical colonies there are certain advantages, or rather attractions there, and the Britisher is always inclined to be adventurous. . . ." I should like to ask him what the attractions are; there are certainly no pecuniary advantages to able and experienced men, and even British telegraph engineers will not adventure for nothing. The author also refers to the serious responsibility of the officers maintaining telephone and telegraph lines "seeing that the [illegible] control of large native populations depends [illegible]rably on the efficient working of the telegraph [illegible] value on this and [illegible] experience and ability to do [illegible] be offered is that the Home [illegible] the ranks.

Mr. W. L. Preece (*in reply*): Before dealing with the [illegible] for not making myself clear on two important points. The [illegible] speakers to modify their views regarding the system to be employed.

Sir [illegible] Pacific Railway Company a short time ago, and I bel[illegible] he told me that he was able to overc[illegible] in the vertical plane. For he found that the [illegible] wind which blew the webs on to the wires being strong enough to break webs connecting wires which were vertically separated. I am, however, speaking here from memory, and I am unable to put my hands on the notes [illegible] say so, I think Sir John has not fully studied the question of solid joints, for he refers to an [illegible] cable is dipped into a bath of hot melted paraffin wax immediately the seal is broken, and as there is a [illegible] vacuum in the cable, the wax is sucked into the cable for a distance of several inches, thoroughly closing the end. It [illegible]nd, so that any ex[illegible]

[illegible] nevertheless believe that if he had had any experience of these real tropics with the damp heat, vegetation, etc., he [illegible] than with a magneto system; in fact sl[illegible] when the insulation is low. There is no a[illegible] central-battery supervisory circuits which [illegible] with the clearing circuit introduced into the Ma[illegible] both are equally advantageous to the user. Th[illegible]

Mr. Preece. But in the tropics the number of calls per hour is invariably lower than is the case in English towns, and the urgency of rapid handling is therefore far less. A central-battery installation costs more to erect and more to maintain, especially in the tropics, than a magneto system. With all due deference to Mr. Cook and to Mr. Slingo, an engineer's duty is to recommend the most suitable system having due regard to the expense of the plant both for installation and maintenance. It is not his duty to recommend to local authorities the latest system just because it has been found the most suitable in other places. Local troubles and local finance must be carefully considered. Both English and American engineers are inclined to treat the central-battery system as a sort of fetish and think it should be employed on every and any occasion without considering the special local conditions. To argue as Mr. Cook does, that because the National Telephone Company were wrong in resisting the introduction of the central-battery system 15 years ago owing to their wires in London being overhead, therefore I am wrong in resisting the use of that system in the tropics, is absurd. In London satisfactory insulation of overhead lines is always obtainable, in the tropics it is not, and can never be under present conditions. The objections raised to the introduction of the central-battery system in England some 15 years ago was mainly due to prejudice and to a fear of the unknown. The objection to the introduction of this system into the tropics is due to knowledge of the special difficulties which would have to be overcome, the unnecessary expense which would be incurred, and the absence of any essential advantage. Overhead lead-covered cables are used and are satisfactory, but to employ an overhead cable when the line consists of only four, six, or eight conductors is not economical and economy is a ruling question in these tropical countries. Also in many cases lines of poles are erected to carry two circuits, and year by year these circuits gradually increase in number. The time may come when the engineer feels himself warranted in dismantling this line and running an aerial cable, but this involves considerable expense which he has fully to justify to his Government. He often finds it less troublesome to continue with the overhead line!

Mr. Cook refers to steel rails and concrete poles, but neither can be used when road transport is necessary. The expense of transport quickly raises the cost of these poles far above that of the Hamilton or other iron pole. Even light iron poles which cost 25s. f.o.b. are found to have cost even £3 by the time they are erected in certain up-country districts. Steel rails are used most successfully on railways, as Mr. McAlpine pointed out, and concrete poles can be used in towns, but for country lines they are out of the question. I have, unfortunately, no meteorological figures at hand to be able to answer Mr. Cook's question on this point. But there is no doubt that in tropical countries of the special type I dealt with, the humidity is always extremely high the whole of the 24 hours and during the greater part of the year.

Mr. Slingo is quite right in saying that the central-battery system has proved itself to be a good, efficient, and economical system in temperate zones. But when difficulties are such that they can only be overcome by a very large expenditure of money, it is not, as I have already said, the function of the engineer to overcome them in order that that system may be applied. If the Mr. Preece. use of a simpler system, which gives sufficient satisfaction, can be obtained at a lower cost, any engineer having due regard for the financial side of the question must recommend the simpler system. Mr. Slingo is perfectly right about the automatic system; it would be unquestionably an immense boon to the population of the tropical towns, and it may yet come. But I doubt if he would be so keen to introduce it, even into this country, if most of his mechanics and attendants were uneducated coloured men, and if his white assistants required more than double the salary they now receive in order to live decently. In the tropics the question of a properly trained staff is far more serious than in any other part of the world. Mr. Slingo, like most English engineers, does not realize this. Mr. Slingo speaks highly of the enamelled wires which pass the British Post Office tests. Unfortunately those which have given trouble had passed those tests, and I hear that the Post Office are not free from similar troubles. I am very glad to hear that glass insulators are being tested by Mr. Slingo. I tried to get some a year or two back, but the difficulty of having them made to fit a standard screwed stalk then blocked the way. Mr. Slingo states that these insulators should be supported by a hard wood pin specially treated. This is a slight drawback and I believe elsewhere iron stalks are used. I sent to Nigeria some of the indestructible insulators to which Mr. Slingo referred; in six months they disintegrated! I must thank him very much for the suggestion to try lightning protectors enclosed in hermetically sealed copper tubes. I have not come across these and I feel sure that they would be well worth testing. Most of the tropical engineers now use the British Post Office type of leading-in wires and find them most satisfactory.

Mr. Slingo mentioned the automatic exchange at Simla. Unfortunately Simla has not a tropical climate at all; it is more like this country.

Mr. Kingsbury is another telephone engineer who does not appear fully to understand the difficulties experienced in the tropics. I have already dealt with the points raised by him.

I am glad to find that both Mr. Weightman and Mr. Laidlaw, who both know a great deal about tropical conditions, agree with my views. Mr. Weightman, in his communication, answers many of the criticisms very conclusively.

Mr. Stubbs raises an important point as regards the difficulty in obtaining information about faulty apparatus. This, however, no longer obtains to any great extent; the engineers now do send home the actual faulty apparatus and detailed particulars regarding its failure. But the difficulty in many cases lies in correctly diagnosing the reasons for the failures, and in reproducing the conditions here which caused the failures there. This was the great impediment to the discovery of the true reason for the breakdown of the coils wound with enamel-insulated wires. Obviously unless one knows the fundamental cause of the fault, one cannot be sure of constructing apparatus which will overcome the troubles. The suggestion of Mr. Stubbs and Mr. Siemens for preventing damage by wild animals is undoubtedly efficacious with cattle, camels, and such-like animals, but when it comes to giraffes, elephants, and monkeys, who can reach the wires in the centre of the spans,

[illegible]

entirely peculiar to the tropics.

[illegible] It is rather remarkable that such women will work in Constantinople, they certainly would not do so in Malaya and have not so far come forward elsewhere.

[illegible]

Mr. Nash spoke from the point of view of the manufacturer, and raised a most important question. The fact that almost every tropical engineer has his own opinion of [illegible] requires does lead to complications in the factory, and certainly tends to increase the cost of the plant. But this trouble is almost insuperable. There can be no central institute or authority which could override the views of the local engineer. No doubt if such discussions as this could be held whilst all the engineers were at home, some important decisions might well result by the ventilation of their several views. Unfortunately never more than two or three are at home at the same time, so that the chances of bringing them and the manufacturers all together are very remote.

[illegible] drew attention to certain important troubles [illegible] great drawback to the use of oil insulators; but it must be pointed out that in the damp tropical climate which I especially referred to, dust is almost non-existent, and if Mr. Sayers found that on the Midland Railway the oil [illegible]

[illegible] This is most important.

[illegible]

Mr. Aitken's remarks have been already [illegible] overcome the new automatic system should be a [illegible] to the tropics.

[illegible] good lightning protection, namely that of having a [illegible] obtain, though not so much so in the damp climate with which this paper is mainly concerned. It is also very desirable to have the earth-wire without turns or [illegible] Most of the colonies find the [illegible] see that Mr. Noble rec[illegible] more elaborate systems [illegible] is a most serious one, of an increased skilled staff, as [illegible] salaries must be far higher than those paid in temperate zones. Mr. Noble's figures of the number of lines per [illegible] suitable salaries for the engineers in tropical countries. I can only hope that they will be read, marked, learnt, and inwardly digested by all tropical Postmaster-Generals and the heads of the various Governments. Also that, as the British Post Office is often asked to supply their engineers to the colonies, the home Engineering Department will make this point quite clear in future.

[illegible] their criticisms. The only chance of [illegible] set forth as fully as possible. The only regret I feel is that it was not possible to discuss completely the subject in the one evening.

TRAINING FOR THE INDUSTRIAL SIDE OF ENGINEERING.

By A. P. M. Fleming, Member.

(*Paper received 2 December, 1914, and read before the* Manchester Local Section 23 *February*, 1915.)

Synopsis.

Introduction.
- Non-technical employment.
  - Selection for trades apprenticeship.
  - Pre-apprenticeship training.
  - Requirements of training for trades apprenticeship.
    - Practical training.
    - Trade instruction.
  - Foreign methods of training.
  - Germany.
  - Other European countries.
  - United States.
  - Trades apprentice schools.
  - British Westinghouse system of trades apprenticeship.
  - Advancement of trades apprentices.
- Technical employment.
  - Classification of employment.
    - Works.
    - Design.
    - Commercial.
  - Methods of training.
  - Technical training.
  - Practical training.
  - British Westinghouse system of engineering apprenticeship.

Conclusions.

Introduction.

In the manufacture of engineering apparatus keen competition has directed increased attention to every factor affecting economic production. Labour—as regards workmen and staff—is one of the most important of these factors, and the object of this paper is to discuss the requirements of training for the various grades of employment in the manufacturing industry and the lines on which such training can most effectively be carried out.

The problem has received much attention from our foreign competitors, especially in connection with the efficient training of workmen. In Germany, for example, the training of youths who intend to enter a manufacturer's works has been dealt with on a national basis. In the United States a similar movement, but on somewhat different lines, has been strongly supported by engineering and other manufacturers. In this country, while a great deal of attention has been paid to the training of the technically educated man, comparatively little has been done, other than by individual employers, to determine and provide the best possible training for youths who are to become skilled workmen.

The grades of employment to be considered may be divided into two classes, namely, those of a non-technical character, and those for which technical training is essential. The former comprises skilled workmen and charge-hands, and the latter such positions as those for works and departmental managers, designers, leading draughtsmen and foremen, testers, and commercial engineers.

Preparation for "non-technical" positions, in so far as it is made at all in this country, is by means of "trade" apprenticeship, for which youths enter works straight from school at the age of from 14 to 16, and are "bound" to a trade until the age of 21. For the "technical" positions many works provide a special practical course, which may be termed "engineering" apprenticeship, the purpose of which is to afford a broad experience in manufacturing processes and methods rather than a high degree of manual skill.

In many works the distinction between "trade" and "engineering" apprenticeship is clearly drawn, in others a "trades" course only is provided. In the latter, the better-educated and most-promising apprentices who have obtained some technical knowledge are allowed wider scope, and thus are fitted in a measure for technical employment. Some works make no effort at all to train men for technical positions, and rely on recruiting their staff from other firms, a policy which in the long run is very short-sighted.

To secure the greatest gain, both to the individual firm and to the industry as a whole, it is important to aim at training each youth so as to develop to the utmost his latent ability, and to prepare him most expeditiously for the position for which his education and ability fit him. If he is capable of rising from the "non-technical" to the "technical" grade of employment, and there is need—as is usually the case—for him in the latter capacity, it is obviously an economic waste to keep him in the ranks. If, on the other hand, he does not possess such ability, it is equally important to train him so as to develop to the fullest extent his capacity as a skilled workman.

While it is important to provide facilities for the able youth to rise from the ranks to a technical position, it is an error to assume that every trade apprentice is capable of so doing and to direct educational efforts solely to that end. The fundamental fact must be recognized that the majority of such apprentices will work at the bench all their lives, and their training should consequently be such as to fit them for this sphere.

Non-technical Employment.

The ordinary workmen comprise three main classes: (*a*) the craftsman or skilled workman, (*b*) the specialist, and (*c*) the unskilled labourer. Of these the first two classes only call for consideration here.

The craftsman and specialist require quite different knowledge and characteristics. The former needs to concentrate considerable thought upon his work, to possess initiative, delicacy of touch, co-ordination between hand

[illegible]

[illegible] machining, press work, and various other branches of electrical manufacture, all fall within the scope of the [illegible]

[illegible] youths who are permitted to enter the skilled trades.

[illegible] for determining the vocational fitness of a youth is engaging considerable attention, the efforts hitherto applied appear to have resulted in very little practical benefit to the engineering trades. In this connection teachers who are in daily contact with youths in the elementary schools could render much assistance by observing those likely to be suited for skilled handicrafts. Apart from more exacting psychological tests, a youth's proficiency in freehand drawing,—indicating co-ordination between hand and eye,—aptitude for handicraft in wood or metals,—as shown by such work done in schools—evidence of [illegible] all indicate to some extent suitability for a skilled trade. If observation on these lines is supported by a first-hand knowledge on the part of the teacher of the requirements of the trade and of its scope and possibilities—a knowledge which should be acquired by study and by visiting engineering works and co-operating with employers—a latent desire for such a vocation might be developed and [illegible]

In view of the various features influencing the choice of a vocation, such as the financial position of the parents and residence in the vicinity of an industrial district, collaboration between the educational authorities and parents may do much to prevent the mortgaging of the future of a youth suitable for the engineering trades by diverting him from the allurements of blind-alley occupations.

Pre-apprenticeship training.—While there is much to be gained by careful selection of the youths permitted to [illegible] the age of [illegible]

[illegible] to develop his mechanical intelligence and [illegible] to appreciate the value of science, to discount rule-of-thumb practice, and to be willing to learn from the knowledge and experience of others.

While there is much [illegible] affords such possibilities of secure employment, coupled with unlimited opportunities of advancement, as that of the engineering trades, and it is [illegible] physique, and greatest intelligence.

[illegible] Under modern conditions the old-time personal relations between master and apprentice are no longer possible. The apprentice nowadays is directly under the control of a foreman, who, while often capable and desirous of teaching him, is more usually burdened so much with routine duties as to be unable to do so. In [illegible] a skilled workman will gladly assist an appre[illegible] in others trade knowledge and experience is jealously guarded.

Under such conditions a great deal of the apprenticeship period is liable to be inefficiently utilized, and even in those works where special efforts are made to teach manual operations correctly, there is a great deal of trade knowledge of importance to an apprentice and which he is unable to obtain readily in the shops.

Suitable training comprises two phases, namely, prac[illegible] to the craft, and trade instruction, *i.e.* a knowledge of the principles underlying the methods and processes employed and of such applications of science as bear on the trade. The former can only be acquired satisfactorily

[illegible]

in the shops, provided the apprentice is not looked upon merely as a producing unit and that systematic means are taken to teach him the manual operations of his craft. Trade instruction can best be dealt with quite separately on the lines suggested later.

Both phases of training should be directed towards giving each apprentice a broad knowledge of his own trade and a general knowledge of those akin to it, so as to discount the narrowing tendency of specialization.

Practical training.—In most engineering works no special facilities are provided for practical training, and an apprentice has usually to pick up such experience as he can in a more or less haphazard fashion. There are of course notable exceptions, and a few firms have well-planned courses and take keen interest in their apprentices, both inside and outside the works. The number of youths thus efficiently trained, however, is exceedingly small, and quite insufficient to have any real influence on the quality of the rising generation of artisans.

In some works instructors are employed to see to the progress of apprentices, and under certain conditions this plan is very satisfactory. In others a separate training shop is provided, as, for example, in certain German and American works referred to later. An example in this country is that of the training shop for instrument makers provided in Mr. Robert Paul's works in London.

In the usual engineering works, where such special means of practical training are not feasible, good results can be obtained if efforts are made to stimulate the interest of the foremen and works staff in the apprentices, on lines such as those referred to later in connection with apprentice schools.

Trade instruction.—The instruction that an apprentice receives during his period of training should be directed primarily to bear on his trade. In most industrial centres, however, the only instruction available is that afforded by evening technical classes, and this, while providing an excellent means by which the ambitious youth can fit himself for technical employment, is usually of little or no assistance to the youth who is to be a workman all his life. Moreover, in most firms it is not compulsory for an apprentice to pursue a course of evening instruction.

In the case of youths who have had suitable pre-apprenticeship education, instruction should comprise the processes applying to the trades and the principles underlying them; the names, description, preparation and uses of the tools and appliances; a knowledge of how to read drawings and diagrams; a knowledge of the physical properties of the materials employed; elementary ideas of the cost of the apparatus produced in the trade; the importance of avoiding waste of time, effort, and materials, and the function of the apparatus or parts manufactured.

It is important that the instructions be so imparted as to stimulate the youth's ambition to attain higher skill, to take pride in his work, and to develop his latent powers of dexterity in workmanship to the utmost. Such trade teaching can be imparted by oral and written means; and this method possesses the important effect of developing a youth's ability to acquire knowledge from other sources than his own personal experience.

Foreign methods of training.—A plan of training that has proved satisfactory in other countries is not necessarily suitable for our conditions, since the character of the people, the system of education, the conditions of employment and of national life have to be taken into consideration. At the same time much can be learnt from the methods adopted in other industrial countries. Some typical features of these are as follows.

Germany.—It has been stated "that the plan of vocational training in Germany must aim at the diminution of economic waste by ensuring that all occupations, however mean, shall be practised by men who have been taught to do their work scientifically."

With foresight and thoroughness, plans have been made to ensure a supply of well-trained workmen in every branch of industry, and with this object vocational training is made an important feature of compulsory continuation education.

Youths are permitted to leave school at the age of 14, but must continue with their education for about 8 hours per week throughout the period of apprenticeship. This compulsory education is carried out for the most part during working hours, employers being required to make provision for the youths' absence from work at stated intervals, such as two half-days or one whole day per week

While the educational scheme varies in different industrial centres, the plan developed by Dr. Kerschensteiner at Munich is becoming recognized as a standard pattern. In this centre, around which there are a number of comparatively small industrial works, separate classes are arranged for the youths of each trade, and in these classes, apart from the continuation of general education, both practical and theoretical instruction is given in the trade by skilled workmen and special instructors.

In the larger industries in Northern Germany it is more usual for an apprentice school to be provided in each works, or collectively for several works; such schools are recognized by the State and their students are exempted from compulsory continuation school studies.

Examples of such schools are those of Messrs. Ludwig Loewe and Messrs. Siemens & Halske. These two firms have also a special training shop for apprentices, in which practical instruction is given. Quoting from a description of the training in the first-mentioned works*:—

> "Not the least important item in works is man—the workman. A thoroughly well-trained body of men that have been long established in the firm represents a huge benefit, and more care should be taken in choosing and training a suitable body of workmen than most firms take. . . .
>
> "We have arranged to provide theoretical instruction in a special school for apprentices, for we are quite convinced that the foremen cannot be expected to impart to apprentices as much theoretical knowledge as they should get in order to do their work properly. The foremen have too many other things to attend to and there is too much noise in the shops; besides, not all foremen are suitable for the task of instructing boys."

Apprenticeship in engineering trades extends over a period of four years, and at the end of this time an apprentice is required to present himself before a committee of experts who examine his knowledge of the trade,

* *Technik und Wirtschaft*, December 1913.

[illegible] is given.

A typical example of complete apprentice training carried out entirely in school is that of the Skiensfjorden's Mechanical School at Porsgrund, Norway. Here about [illegible] training during a 3-year course, part of each day being spent in class and part in school workshops. The results [illegible]

United States.—In the United States there is as yet no national scheme for the vocational training of juvenile workers, although much has been done in this direction by individual employers in various industries. In the engineering trades youths as a rule enter works straight from school, and in the past the general tendency has [illegible] In some industrial centres around which a number of comparatively small works are situated, special schools for the trade instruction of apprentices have been established. These are usually controlled by the local educational authorities. Prominent examples are the State Trade [illegible] in Massachusetts, and the Cincinnati Continuation School. [illegible] combined to support a trade school, which subsequently came under the control of the local educational authority.

In some of these trade schools youths attend classes on [illegible], and in this way disorganization and loss [illegible] of machine tools is avoided.

[illegible]

[illegible]

[illegible] use of one particular tool or process, and then proceeds [illegible] process, and so on till the end of his apprenticeship. [illegible] a certain number of hours per week.

In the General Electric Company the apprentice [illegible] all his time of training either in class or in the training shop. In the latter he is moved progressively from machine to machine, his proficiency being gauged by when he is able efficiently to "break in" the youth who succeeds him.

A 4-year period of apprenticeship is becoming customary in the largest works.

The lack of facilities for evening instruction favours the development of the apprentice school, and the large foreign-born population necessitates the provision of a considerable amount of general education in addition to that required for trade purposes.

[illegible] been taken in the development of the apprentice-school method of training, and most of the large works in every kind of industry are adopting this plan. An association known as the National Association of Corporation Schools has been formed for linking up the efforts of the various firms interested in this method of training apprentices.

[illegible] various industrial countries that have been considered, the combination of practical training either in works or in special training shops and of trade teaching in class is that most favoured for the training of workmen. The principle thus embodied is by no means novel in this country, having been adopted very many years ago in the training of naval engineers and dockyard apprentices, and also by certain manufacturing firms.

The apprentice school attached to works represents the [illegible] conditions for a part of each day, and [illegible] certain of the working hours. In this way there is little time lost in getting to and from work, and instruction is more readily assimilated than by evening study. A close link is formed between the apprentices and the staff; the difficulties that the former experience in their everyday [illegible] with special features peculiar to individual works [illegible]

readily adaptable, for example, to the explanation of special kinds of tools or apparatus, and the most efficient methods of handling or assembling can be demonstrated. Where a number of youths are employed in the same kind of work, it is cheaper and more expedient to teach them the best methods collectively by an experienced instructor, than individually by several people of indifferent ability.

The close supervision possible in an apprenticeship school enables those apprentices deserving of promotion to be readily selected. In this way the interest of the remainder is increased, and a spirit of emulation is aroused.

*British Westinghouse Company's system of trades apprenticeship.**—The apprentice-school method of instruction has been adopted by this company, and serves as an illustration of the general working of this plan of training.

The trades to be dealt with include pattern-making, moulding, core-making, fitting, turning, tool-making, electrical assembling, instrument-making, armature-winding, tinsmiths, and various divisions of specialized work. Also training is required for draughting, testing, and other employment such as estimating, accounting, and commercial correspondence.

Instruction averaging about five hours per week is given during working hours to all "bound" apprentices, numbering altogether about 300 in a school situated in the works. The regular rate of wages is paid during the time spent in study, and all the cost of books and stationery is borne by the firm.

Candidates for apprenticeship are carefully selected according to their educational qualifications and moral character, and after passing a probationary period, which is intended to test their fitness for practical work, they are admitted to the school.

The instruction is divided into two classes, "General" and "Trade." The general education is a continuation of the apprentices' regular education, and includes an elementary knowledge of science. On account of the comparatively low standard of education possessed by the average apprentice, considerable attention has had to be paid to this class. By careful selection of apprentices, however, it will not in future be necessary to devote so much time to the general education, and more attention can be paid to the trade instruction, which is of primary importance.

The teaching is done by 12 members of the firm's engineering staff, supplemented by lectures from the leading foremen and shop engineers, which deal specially with the trade subjects.

The contact between the foremen and apprentices in the school produces excellent results, and removes the diffidence which many of the apprentices feel in approaching the foremen with their difficulties. Where it is required to illustrate special processes or describe particular apparatus, which cannot readily be done in the school by lantern projection or drawings, practical demonstrations are given in the works.

A committee of apprentices, elected from amongst themselves and representative of the different trades, co-operates with the lecturing staff. This committee also takes control of the library of the school. In this library, trade catalogues and publications figure largely.

The most promising of the apprentices are selected for work in the testing departments and drawing office, and in other respects are allowed a wider range of work than that covered by their own trade. Each year about 10 apprentices are selected as a result of their school work and shop progress, and sent for one whole day each week to the course for engineering apprentices at the Manchester Municipal School of Technology. The cost of tuition, books, etc., is borne by the firm, and no deduction is made from wages during the time spent at the school. Such youths are marked for advancement in the company's service as suitable opportunities occur.

Through their work in the school the interest of the foremen is aroused, and as a result increased attention is paid by them in the shops to the practical training of apprentices.

This apprentice school has only been in operation for about a year, but so far the results both from the point of the company and of the apprentices are most encouraging.

Advancement of trades apprentices.—While the primary function of the apprentice school is to prepare youths to become good workmen, its secondary object is to enable a selection to be made of promising youths for promotion to positions where they can be more advantageously employed, as, for instance, charge hands, foremen, and inspectors; and in this connection as the quality of the workers is improved, it is probable that the standard of the foremen will require to be adjusted accordingly.

In addition to such positions, the apprentice school affords a ready means of selecting apprentices who can profit by technical training and rise to higher posts. By promoting some of the apprentices on account of merit in this manner, encouragement is given to all the remainder to strive for advancement, and the results are beneficial alike both to employers and employees.

The provision of a channel whereby an apprentice can rise from non-technical to technical employment is a most desirable feature and should be given every encouragment.

Technical Employment.

Almost every engineering commodity is now manufactured in large quantities, by standardized operations, and organization is planned to secure the most economical production possible. A technically trained engineer who enters a manufacturer's works and intends to remain in that branch of the industry, therefore, requires quite different training from that of one who ultimately expects to take up, for example, civil engineering, operating work, or the broader scope met with in colonial engineering.

The various kinds of technical employment in engineering manufacture are as follows :—

(1) The works side, including such positions as works and departmental managers, shop engineers, leading foremen, assistants in the inspection, testing, estimating, and drafting departments.
(2) Designers.
(3) Commercial engineers.

Works.—The works side affords an increasing scope for technically-trained men possessing a bent for organization,

* For more complete details of this system see report of discussion on "The Education of Engineers" before the Manchester Association of Engineers, 14 November, 1914.

[illegible] labour and [illegible] manufacturing [illegible] economic [illegible]

[illegible]

[illegible] to follow up new [illegible] manufacture, and where necessary to alter existing designs so as to enable the most economic and up-to-date methods [illegible] tion, certain American works have employed what is there termed "efficiency engineers."

Shop engineers require good technical training, suitable shop practice, and drawing-office experience.

Apart from these positions, important vacancies in the estimating department should be filled by technically-trained men who have an intelligent understanding of works processes. Such men are in a position to detect leakages and determine where economies in working can be effected, which are likely to be overlooked if ordinary clerical labour is employed. In the testing department the leading men should also have good technical training. This department is the backbone of the designing office, and scientifically-trained intelligence there is invaluable.

Design.—For this branch, scientific training is indispensable, and a great many technically-trained students look to it for their future employment. It is not suffi- [illegible] experience in the shops, including an intimate knowledge of manufacturing costs and processes, is invaluable. In this respect lies the principal difference between the training of the designing engineer in this country and that in Germany. In the latter country practical experience is to a very large extent dispensed with, and greater weight is placed on scientific training.

Apart from its direct value, works experience is essential in developing the intuitive capacity which [illegible]

[illegible] what the works [illegible]

[illegible] a considerable amount of [illegible]

[illegible] all of which have been discussed from time to time by [illegible]

(a) [illegible] applicable to manufacturing, and an [illegible] suitable means for the advancement of able youths has already been set forth in connection with the [illegible]

(b) [illegible] college course, followed by works [illegible] This plan was recommended by the Institution of [illegible] found in arranging such a course with manufac- [illegible] which is liable to follow from an apprentice [illegible] difficulty is not an insurmountable one, and the [illegible] by evening study for the matriculation or other entrance examinations required by the technical school. In other respects this plan is very well [illegible]

(c) [illegible] course, except for the p[illegible]

(d) [illegible] ing periods. This sandwiching system has been employed to a large extent in Scotland, where the method is most adaptable to the arrangement of [illegible]

[illegible]

Northampton Polytechnic Institute, and, on somewhat different lines, the Faraday House Electrical Engineering College. Other prominent institutions have also adopted this system to some extent. The method does not, however, find much favour with some manufacturers, who object to the disorganization which it tends to produce.

(*e*) By taking a complete works apprenticeship prior to the technical training. This is not a satisfactory method for training for technical positions in manufacturing.

Of these plans, (*a*), (*b*), and (*c*) are most suitable from the manufacturer's point of view; but whichever method is adopted, it is desirable that the practical training should terminate in the works, since a better opportunity is afforded to the student for obtaining permanent employment with the firm in which he has obtained his training. It is also most important that the entire training be preceded by thoroughly sound general education.

Technical training.—Since most students have little idea at the commencement of their studies as to what branch of employment they will subsequently enter, it is impracticable, even if it were desirable, for college authorities to direct technical training along specialized lines. On the other hand, much more could be done to keep before the student the importance and possibilities of the manufacturing side of the industry, particularly in regard to the works section, as already noted. In this connection, technical studies might with advantage include works organization, costing, and estimating, and attention might be directed to trade journals with a view to the appreciation by the student of manufacturing problems. Such subjects are at present included only in the syllabus of a few of the leading technical schools.

A matter of importance in connection with the technical training is the absence at present of effective means for eliminating at an early stage students who are unsuited for the engineering profession. Discrimination in this respect appears to be most satisfactorily effected where the training is carried out on the sandwich system, since the fitness or otherwise of many young men is not fully shown up until they attempt to undertake practical training.

Practical training.—There is a wide diversity of opinion as to how long a period of practical training a technically educated young man should have, and what its nature should be. Some firms adhere to the 5-year apprenticeship scheme as applying to all young men, whether they are being trained as workmen or for technical positions, but the more modern tendency is to arrange a shortened course for the latter.

The position is analogous to the training of officers for the Army. Not every officer rises from the ranks, although there are facilities for so doing. The more usual course for one possessing sufficient education and other requisite characteristics is to enter an officers' training corps, or by other similar means acquire in the most efficient and expeditious manner the experience required for his position.

Similarly in regard to the young man who is to be specially trained for a staff position in a manufacturing organization; while long practical experience is excellent, it is not the most effective method of attaining the end in view. Moreover, a man who has had his intelligence developed by a technical-college course should be able to acquire practical experience at a much quicker rate than one not so educated. In view of this, and bearing in mind that both in Germany and the United States a 4-year course of practical training has been found to give satisfactory results, even for youths who intend to be workmen all their lives, a shorter course than this would appear to meet the needs of men trained for the staff. The object of practical training for such positions is to afford an insight into manufacturing methods and economics, and to acquire a knowledge of how to handle men.

British Westinghouse plan of training "engineering" apprentices.—In addition to the arrangements for training "trades" apprentices already described, this company has for the past 12 years trained "engineering" apprentices according to certain well-defined courses.

Young men of the age of 20 and upwards, who have had a thorough scientific training at a university and possess an Honours degree in Engineering or are in other respects considered eligible, are admitted to a 2-year course of apprenticeship on the recommendation of their college authorities.

Young men of from 18 to 20 who have had a good technical education are apprenticed for three years.

A further course of four years' duration applies to youths of over 16 years of age who possess a good general education and some elementary technical knowledge. This latter course is gradually becoming superseded, and such youths more usually enter the "trades" course where, with their superior education, they have ample opportunity of advancement to a technical position.

These "engineering" apprentices are placed either in the electrical or the engine side of the works, according to which of these two branches their technical training has been directed. In the former the shop experience comprises work in such departments as those for the manufacture of large electric generators, motors, transformers, switchgear, controllers, detail apparatus, instruments, etc. The latter includes the departments for gas and Diesel engines, turbines, and condensers, and the foundry, patternshop, etc. In addition to the manufacturing departments, the apprentices have opportunities for entering the testing departments, drawing-office, designing, and commercial departments. They are moved from department to department, as a rule every few months, and every endeavour is made to develop the apprentice's capacity by giving him responsible work to do. The first 6 months of apprenticeship are served on probation.

The object of these courses is to train suitable young men for the company's service in either the works, or design departments, or in the commercial sections of the organization at home and abroad. In the works they acquire experience in manufacturing requirements, become thoroughly acquainted with the wide range of apparatus manufactured by the firm, and in so doing develop their bent for one or other of the divisions of employment in which to specialize. Prior to the end of their course of training apprentices are usually placed in one or more staff positions on trial.

Heretofore, during apprenticeship, only a nominal rate of wages has been paid. Owing, however, to the fact that many promising young men have on this account been

[illegible]

[illegible]

[illegible] justifies concerted steps being taken by manufacturers [illegible]

In the case of the "rank and file" of workers it is first [illegible] mines the quality of the workman. In the selection of youths employers should realize their individual responsibility and appreciate that every inefficient youth admitted to engineering employment is a handicap to the industry.

Special pre-apprenticeship instruction is desirable, both as a [illegible] for entrance to works. The various difficulties that this instruction presents could generally be surmounted by close co-operation between employers and educational authorities in industrial centres.

Having secured suitable material for trades apprenticeship, the function of the subsequent training is two-fold. One is to select those youths who possess the ability to profit by technical instruction, and to provide for such youths facilities for their advancement to positions where their capabilities may be fully utilized. The other is to train youths lacking in such ability so as best to fulfil their function as workmen.

In the efficient training of the latter two requirements must be provided—manual experience and trade instruction. In regard to manual instruction a separate training shop in a works offers many advantages; and, failing this, a special apprentice instructor. These means are, however, not widely applicable, and in their absence it is necessary for each employer to take steps to ensure that the foreman and works staff give personal attention to the training of the apprentices under their charge. In most engineering works such attention is almost entirely [illegible]

[illegible] to trade instruction, the evening technical [illegible] in most industrial centres are quite un- [illegible] compelled by their employers to attend classes for suitable [illegible] value to apprentices and teachers alike, would serve to keep instruction throughout the industry of the same character, and would prevent teachers drifting from [illegible] is almost inevitable.

[illegible] important that the training be arranged on such uniform [illegible] ence that different firms have to offer. Some guidance as to the duration of apprenticeship and conditions of employment would, however, be desirable.

[illegible] trained men in works organization, and to the fact that except in isolated cases the technical colleges have neglected to give attention to this field of employment.

In connection with the training for all positions whether of a technical or non-technical character, the importance of securing the best possible material cannot be over-emphasized, and it is [illegible] to place any obstacle [illegible]

[illegible] money and service thus expended may be viewed in the light of an investment.

[illegible] fact that trades apprentices, as a result of careful training, mature at an earlier age than those not so trained. Also, owing to their ability to read drawings and make shop calculations, they require less supervision and assistance from their foremen. The quality of their work is superior, and apart from saving direct labour costs, indirect expenses may be favourably affected if the principles of efficient working have been taught. Improved relations between employers and employees may be looked for as a result of this attention to juvenile labour.

[illegible] manufacturers, the tendency for workers to move around from works to works in search of wider experience would probably be reduced, and, as an indirect result, considerable economy would be effected, the cost of engaging and [illegible] usually thought to be the case.

[illegible]

Discussion.

Professor Marchant.

Professor E. W. Marchant: It is particularly interesting to those who are engaged in the education of engineers to have the opinion of one who has had many students through his hands, and I think a paper of this kind will be of great assistance to us. In the first place, I should like to say a few words about that part of the paper which deals with the training of trade apprentices. The author says that, on the whole, evening classes are not regarded with favour. Personally, I am very glad indeed to know that such is the case, because it seems to me that it is a physical impossibility for a man who has been engaged in manual or other labour during the daytime to study effectively if he gets his technical education in the evening. The company with which the author is associated is to be congratulated on having devised a scheme by which apprentices will have the opportunity of gaining some knowledge of the theoretical technique of their profession during the daytime. Another point is the author's statement, which I think cannot be too strongly emphasized, that the fitness of a man for the profession of engineering depends essentially upon his own inherent characteristics. That is a dictum which holds good not only for the trade apprentice but also for the technically trained man; every boy who enters a college to receive training in engineering is not necessarily one who will make an engineer. In the University of Liverpool we have made an attempt to ensure, as far as we can, that those who are taking the three years' course in engineering shall be such as have at any rate some reasonable prospect of being successful when they take it up in practice. Otherwise numerous persons leave the college who are nominally engineers, but who have no chance of succeeding in the profession which they have adopted. This is bad, not only for the men so trained, but for the university which trains them. I come next to the college-trained student, with whom of course I have most to do. The main point, so far as we are concerned, is not so much technical knowledge as breadth of view. I think nobody now expects that after a three years' course at college a man should have become a properly trained engineer. To do this is impossible. All that can be done is to instil into the pupil while he is at college a certain number of fundamental principles. As Mr. Peck once put it, "What one wants to specialize upon is fundamental principles." The more I see of the education of engineering students the more I recognize that that is the thing which we should do above everything else. I put down as the two subjects which seem to me to be fundamental in the profession of engineering—Engineering Drawing and Designing and Applied Mechanics. We come then to the other more specialized subjects, namely, Electrical Engineering, Mechanical Engineering, Civil Engineering, etc. We must give a good training also in these subjects. In my view, although it may appear to be diverging from what I have just said, the most effective way in which we can train a man after we have given him his fundamental principles—I do not mean merely in those two subjects, but also in the others—is by allowing him, if he shows any capacity at all, to carry out some original investigation or special test on his own account. If we train in fundamental principles and combine with this a certain amount of training in scientific investigation, or scientific design of machinery, we get a course which will ultimately produce a competent well-trained technical engineer. It is an old saying that what matters in a man's training is not what he knows but how he has learnt it. His point of view is far more important than the facts which he has been able to get, most of which, after all, he can get out of an encyclopædia. I do not say that we should not give him facts—everybody will acknowledge that we must—but I think the main thing that we can help to give him is a proper point of view. I should like to refer to another very pertinent subject; that is, the type of training which is most suitable for a technically trained man, *i.e.* whether he shall come to college first or whether he shall go to works first. I am very pleased to find that the author supports the view that the college should come first. That is the plan which we have adopted or recommended, as far as we can, for our students, and as far as my experience goes that plan has worked out best in practice. The arguments in favour of it from the works' point of view have been stated by the author; the arguments in favour of it from the educational point of view are obvious. A boy, when he leaves school, is far better able to take advantage of a college course than he will be after spending some time in a works. Personally I do not very much like the "sandwich" system, although one recognizes the advantages of it; I should also like to say this, that although I am in favour of the "college first" system, I do not think it is a system which applies to all branches of engineering. In the Navy the plan of sending a constructor through a course of dockyard instruction has proved very successful, at any rate as far as we are able to judge from what has been happening during the last few weeks. Therefore, although I think that in electrical engineering, in which the technique is extremely difficult and the mathematical knowledge required is considerable, "college first" training is best, I do not think that holds good for all kinds of engineers. I come now to what seems to me to be the crux of the position, and one which I am very glad the author recognizes, namely, that if the industry of engineering is to develop and progress it must attract into it the best type of person. To do that, one must make the opportunities for those who enter electrical engineering as good as one can. I am very glad to see what is being done by the British Westinghouse Company. The fact that they recognize that the technically trained man is so useful that it pays them to give him a living wage from the time he enters their service is an extremely important development. It will have an enormous effect upon the students; it will tend to encourage them and will help to retain in the engineering industry those whom one wishes particularly to retain.

Mr. Mensforth.

Mr. H. Mensforth: I should like the author to define what technical education means. We have heard what Professor Marchant has said from his point of view, which to my mind is more or less academic. He mentioned mathematical ability. I should say that if 5 per cent of our people are clever mathematicians we can get along very well in that respect. It is the other 95 per cent whom we have to deal with. One thing that has not

[illegible] and would [illegible] learned a good deal [illegible] certain amount of technical education or (to use Professor Marchant's words) has learned the fundamentals of [illegible] the character. Our difficulty is to get out of the men what we ought to get; in other words, if we could appeal to them on the proper lines there would be no difficulty in increasing our output by 25 per cent. I think that applies to most engineering concerns. As a rule the men who run the works are not technically educated because technically-educated men are not available for that purpose. The men who run the works are generally artisans who have got rather more common sense than their associates and have consequently been advanced. If our technical colleges and schools can do anything at all to assist us in that respect by pointing out to their students the opportunities which this side of the profession offers, we [illegible]

Professor Miles Walker: The author has very properly emphasized the importance of trade education and manual training for trade apprentices. This is a matter which we have not really discussed here before, although the subject of technical training for engineers has often been considered. As Mr. Mensforth has pointed out, it is of enormous importance, for it affects 95 per cent of the men, while technical training concerns only 5 per cent. The author is to be congratulated upon the way in which he has carried out in practice the principles that he has laid down. It is important to draw a distinction between what we may call trade instruction and technical instruction—not merely in the thing itself, but also in the character of the school where that instruction is to be obtained. In the Manchester School of Technology our efforts are mainly directed to technical training, and we have a sufficient demand for it, both in the day and in the evening classes. We deal with hundreds of men in the [illegible] There is [illegible]

[illegible] now to what may be ca[illegible] But while we devote most of our attention to these we [illegible] tunity arises, to what may be called "trade classes," or as the Board of Education now terms them, "minor courses"—such as classes for wiremen, plumbers, Post [illegible] and so on. We cannot do all that is necessary to meet [illegible] attention is directed specially to technical education It would require an exceedingly large building perhaps three or four times as large as our present building in Sackville-street, to deal adequately with trade classes and manual training. The difference in the [illegible] fairly well illustrated by reference t[illegible] cipal Engineering, for instance, and the course in what we call Plumbers' Work. The first-year course in Municipal Engineering includes the following subjects:—Chemistry of the non-metals, chemical laboratory, physics, physics laboratory, mathematics. These subjects clearly form the theoretical groundwork of a technical course. [illegible] tical work. In teaching these subjects, examples are taken which appeal at once to the practical plumber. The subjects are taught in an elementary way, so as to be grasped by the type of student that takes a trade course. While we include in our Evening Calendar quite a number of these trade or minor courses, we do not have sufficient facilities for doing the work on a more exte[illegible] We ought to have in Manchester an ex[illegible] institution dealing with apprentices from all the different trades, and showing them the principles which underlie their trades. That should be done, if possible, in the daytime, as the author suggests. Of course, it will be a very big business to undertake. It is hardly fair to [illegible] his works for the [illegible] ought to be a national system carried out exactly in the same way as we carry out the technical ins[illegible]

Professor Walker.

would increase enormously the efficiency of the workman. In order to bring into existence a really good school of this kind, it would be well if a number of the manufacturers in the neighbourhood would form a committee, which would consider the right steps to take and bring pressure to bear upon the proper authorities. Mr. Maxwell Garnett has already proposed the formation of such a committee. In addition to the actual knowledge and manual skill gained at the technical school, we have taken into account the effect upon the moral character of the men. We can improve matters as to the way in which a man looks at his work and the importance that he attaches to it as compared with other things. If from the first an apprentice is put under the influence of a teacher who deals not merely with the technique of the work, but also with such aspects of moral character as control or affect the production of the work, it will be an enormous benefit. Professor Marchant referred to the importance of having college training before works training. I am quite in agreement with him on that point, and it is interesting to note that in its last Report the Committee appointed by the Institution of Civil Engineers to consider the subject is in favour of college first. Even the minority were in favour of just one year at the works and then college. There is no doubt considerable benefit to a student who can spend a year in a works before going to college. If his parents are well off, there should be no difficulty in his staying for a year at a works first, where he will have to turn up at 7 o'clock in the morning and "rough it" with the other workmen. His experience will make it easier for him in the college afterwards; but he must look upon that year as a year extra, and it must not be deducted from his college training; nor does it replace the two years' works apprenticeship. In that first year he will learn mainly discipline, and a good deal about his ignorance of engineering.

Mr. Paton.

Mr. J. L. PATON: I take it that the schoolmaster really comes into this subject in two ways. First of all, his business is to discover the right boys for the engineering profession. There can be no doubt whatever about the supply of boys; of every 10 boys who enter the Manchester Grammar School at least six, probably seven, want to be engineers. The tramway system, the electric bells in the house, the provision of such toys as Meccano of which new editions are produced every year, the fact also that we have scale model engines, turn the minds of boys in the direction of engineering to an extent that was certainly not the case 12 years ago. They are all anxious to qualify for that profession and the first thing that I say to them is, "Well, you will have to work and be thorough because in engineering they always (as we say in Scotland) fire out the fools." I try to get a hold upon them in that way. So there is no likelihood of an inadequate supply of young fellows ambitious to become engineers; and for the schoolmaster who has to direct their study and advise the boys who are intending to become engineers it is an extremely valuable and interesting experience to come to such a meeting as this and learn what the operations are in which they will be engaged and how drawing, applied mechanics, and things of that kind are going to tell in their actual life work. Then, of course, our second duty is to get into their minds a sense of duty and a certain amount of mathematics, geometry, and mechanics. I am very glad that the author lays down as axiomatic that every boy who starts at the works ought to have the chance of attaining, if he is capable of it, even the author's own position. Not long ago I read a paper by Mr. Marquis of Liverpool on "Upward Mobility in the Cotton Trade." He proved by statistics that of those in leading positions in that trade, heads of firms and heads of departments, over 50 per cent (if my memory serves me right) had risen from the ranks. Mr. Marquis rightly traced the vitality of our cotton industry against all competitors largely to the fact that it is democratic and that any man who has got it in him has the chance to rise. It is important that every boy should feel that if he has the capacity he can climb to the top of the tree. That involves, I suppose, the abolition of premiums. I have not heard them mentioned and I take it that if we are desirous of seeking out capacity we must not set up any barrier in the way of upward mobility. We must not put any tariff on ability. Among the Ancoats lads I am very much impressed by their lack of interest in their work; if questioned about it they say, "It is all right," or "There's nothing to grumble about," but I very rarely find one who is keen upon his work. I think the reason is simply that the lad of that class is looked upon as a producing machine; he is put down at one machine at one job, which becomes exceedingly monotonous and he feels no interest in it, and he does not see what relation it has to the whole or the part which it plays in the economy of the world, in meeting the needs of his fellow-men. I want to put in a plea for the "bottom dog." In the course of his paper the author quoted some very striking words. They came from Germany. He says on page 568, "it has been stated that the plan of vocational training in Germany must aim at the diminution of economic waste by ensuring that all occupations, however mean,"—I should like to underline those last two words—"shall be practised by men who have been taught to do their work scientifically." I endorse that view and I think we need not go to Germany to find it. In the Navy every man is taught to do his job scientifically. He may be a stoker who has signed on for a short period, but nevertheless he goes into a class; he learns all about stoking, but he also learns something about the running of engines and he is kept in touch with his own English language and literature. The result is that when the stoker comes out from his period of service he can always find a job. Large numbers of Army men pass through an Unemployment Bureau, but it is very rarely that one of our Navy handymen is found on the unemployment register. I believe there were until recently at least 10,000 of them in London working as engineers, chauffeurs, and so on. Not only do the dockyard apprentices receive technical intruction, but every man in the Navy is kept in touch with the intellectual and scientific side of his work and the "bottom dog" is not forgotten. After all it is in the utilization of waste products that Germany excels — but the most wicked waste of all is the waste of men. Even the "bottom dog" is a man. The spirit in which the unskilled labourer does his work must make a vast difference in the spirit of the works as a whole and in the output. One advantage which appeals to me in connection with the scheme at Munich is that Dr. Kerschensteiner succeeded in getting

[illegible] the distributing side also, but I am not alluding to that at [illegible] school approved by the Association ; then for a period of [illegible] at the service of the Association which has provided largely for his training. He has definite prospects with them. Now that is the human element. I am not competent to discuss the technical element in this problem, but I should like to lay stress upon the place that the human element plays in the solution of this problem. In the case of a physical problem a wise man at the university will sit down and think the thing out, and by virtue of superior brain capacity he will lay down exactly the lines on which the problem is to be solved. But engineers have got a human problem to solve and they can only solve it by getting the hearty concurrence and co-operation of every unit that is concerned. The various groups of firms involved in these trades, and the various human units—including the untrained man, the unskilled labourer, and the "bottom dog"—must co-operate for a common end and we shall then have the atmosphere in which this great problem can be satisfactorily solved.

Mr. A. J. CRIDGE: There are several reasons why this subject of training those who work with their hands rather than their heads has been in the background. The first is, I suppose, that the problem is rather different from the training of the engineer ; there are many more men, and as a rule they have less money and time to spend on their education. Another is, I think, that skilled direction can frequently get good results even out of imperfectly trained men, not of course at so high an efficiency as if they were properly trained, nor at so low a cost. Throughout this paper, and indeed throughout most of the papers that have been written and most of the speeches that have been made in the discussion of papers on this question, [illegible] results in the near future. Co-ordination [illegible] the extent that it should do between the employers and [illegible] There are notable exceptions to that; some of them are [illegible] dealing with what he has to analyse are very different from those which we find in the laboratories of a university. [illegible] book which was written by the present author and Mr. [illegible] what was done on that line. More recently, on the 12th of [illegible] his presidential address to the Institute of Locomotive [illegible] the General Electric Company of America is described in [illegible] clear to everyone that to have a school for apprentices is only possible for a large undertaking, and Mr. Yarrow, speaking on Professor Dalby's paper which I mentioned [illegible] small or moderate size to have such a school. But I think something could be done here by co-operation. The work which has been done by Dr. Kerschensteiner of Munich in having separate classes for youths employed at small local [illegible] namely, the nationalization of the training of the artisan classes in manual work. Now, with regard to the question [illegible] seems to me that the layman is practically certain to come to the conclusion that the "sandwich" system is [illegible] expert opinion in favour of each. If the student goes to [illegible]

[illegible]

what he has to learn. Further, as Mr. W. H. Maw, a Past President of the Institution of Mechanical Engineers has said, "it is no uncommon thing for a young engineer after a few months in the workshop to realize what opportunities he has missed while he was at college." On the other hand, college training before works' experience gives theoretical knowledge which enables the student to understand better the machines and operations with which he afterwards comes in contact. It seems to me that both those advantages can be gained by the "sandwich" system, and not otherwise, and this system breaks the monotony of a complete works course or a complete college course. Professor Marchant mentioned that it takes a great deal out of a student to have to attend evening classes after he has done a good day's work. Therefore it would appear that teaching in works is the right thing. Correspondence tuition has not been mentioned by the author—indeed I have seen no reference to it in discussions of this character. I think such tuition requires more concentration and earnestness than a young fellow is generally prepared to give, principally because he has not been trained to give it. I am very pleased to see the financial difficulty removed. Some people have said to me, "If you pay the young fellow self-supporting wages while he is learning it gives him a great idea of himself and makes him think that he is worth quite a lot to the Company." I think that view is entirely wrong and shows an incorrect appreciation of human nature. I am also glad to notice that the results obtained at the works of the British Westinghouse Company seem to be very satisfactory. One gathers from the remarks which are made by people in the Press from time to time, that it is not always the case that apprentices who have plenty of opportunities are prepared to profit by them. Then I am glad to see that the author gives some weight to the commercial side of the question. At the same time, there seems lately to have been a tendency to exalt it at the expense of the engineering side, particularly in central-station work, but I think everyone will agree that the commercial man without engineering knowledge is not so satisfactory at the head of affairs as an engineer without commercial experience would be; probably he would be far less competent to deal with trouble. Many people who go in for engineering seem, however, to despise commercial ability. I think that is a pity. One argument against training an apprentice in the works is that he may afterwards go elsewhere and give a competitor the benefit of his training. My reply to that is that we cannot expect a man to be bound to us for the whole term of his life because we have trained him—we must pay him properly and so keep him. I think we should get somewhere near the condition which obtains in the steel and silversmiths' trades in Sheffield; that is, that men occupy the same position and do good work at very good pay for 20 or 30 years, or even more than that. This may not appeal to the advocate of "hustle," but it stands for excellence. The author says that recruiting from other firms is a short-sighted policy. By training men and paying them well we raise the level of general ability, and we certainly lay up for ourselves a reward in the shape of increasing business and big dividends. The author mentions the training of works organizers. Is it possible to train them? I do not know what colleges go in for training in this matter of works organization. Perhaps the author can tell us of some. Lastly, we must find some means of bringing the papers read and the discussions which take place on this subject before the parents and guardians of the future students, for they are the people to whom we must look for the future supply of students for the profession.

Mr. Tho

Mr. E. THOMAS: This subject interests me very greatly, for I had 12 years' experience in an engineering college, and have had nearly 20 years' experience since in commercial engineering. I find myself very much in sympathy with Mr. Mensforth's views; we only want the education that will yield practical results against trade rivals—especially foreign ones. It has been recognized rightly that practical experience and an engineering instinct come first and are absolutely indispensable. It was left to the workshops to provide the practical training, and these simply allowed men to pick up good and bad methods alike without any attempt at guidance. This paper and the great number of discussions on technical training which have lately taken place indicate that workshop managers now realize that real instruction is wanted for the workshop, and that technically trained men are necessary in these days of aniline dyes, alternating currents, etc. It is also realized that we have a lot of ground to make up. I wish specially to urge that the practical man is now in the right mood to join hands with the technical authorities. The Government would welcome such a combination and would willingly find the means to enable any suitable man to get a sound training whatever his circumstances. But the men to represent the workshops in this collaboration should be the really practical men—designers, foremen, estimators, etc.—and not heads of firms, as the latter are not in the same intimate contact with the requirements. The author has said very little as to the actual courses of instruction given. It would be useful if he would add something on this point. I would suggest that there are three main classes of training required: (1) Industrial training; by example, instruction, and reward. Repetition workers need this but may easily be spoilt if the attempt is made to make them think. (2) Training for tool-fitters, etc. This follows (1) for suitable men and includes training in thinking. It should be essentially practical and by good and bad examples from the practice of the actual shop. (3) Training for thinkers, *i.e.* for men who design and who analyse requirements and troubles. It should be a very practical course; less mathematical and abstract or academic work. Such a course should include rate fixing and estimating, taught by rate fixers and estimators respectively. These subjects force an intimate consideration of (1) and (2). This course should be for two years, and should include less laboratory and mathematical work, and much more exercise work from practical examples. A third and even fourth year's course could be provided for those few who are worth it, and in such courses more mathematical and advanced work would be taken and some side subjects. The keynotes of these courses are: It is not desirable to try to train all repetition workers to think. If one attempts to do so, one will fail and may spoil their quickness. It is desirable for a college training to keep in contact with the money side through rate fixing and estimating courses. It is of first importance to encourage the engineering instinct and discourage the academic. I urge that the Institution

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[illegible] I have known such men but they are frequently unhappy because they are not allowed to con- [illegible] scapegoats to be sacrificed in the presence of enraged [illegible] [illegible] atter of time saving and proper control, [illegible] students are allowed to study machines of other makes, their experience will be very narrow, and for this reason I think independent schools are more satisfactory. I hope that the ideas of training put forward by the author will soon become accepted by firms in general, as I find that the great complaint of university men is that their special scientific knowledge is exploited by [illegible] or on the test-plate where he will be most useful to the manufacturer without regard to the man's future. It is thus that men drift into the sales department where a good address and a ready tongue, coupled with a general smattering of engineering, seems to be all that is necessary. The [illegible]turer, however, is not the only one who must be [illegible] for the student himself is sometimes to blame. I [illegible] as they can do a certain class of work; the obvious reply is that if they could not do it they would not be there. Students fresh from college are apt to forget that a works has to pay and that they cannot be pushed on as fast as they have been accustomed to when at college. As I move about I find many youths who are entirely [illegible] for engineers, but who fill up the ranks and [illegible] common labourer. It is lamentable to see young men on

[illegible] individual man.

[illegible] come into central stations with great hopes and [illegible] which are very often shared by those who are responsible for selecting their profession; but, partly owing to the character of the work in central stations, and partly [illegible] and it is only in exceptional cases w[illegible] found. Whilst firms like the British W[illegible] Company are making efforts towards the training and education of their apprentices I sometimes think they are undoing this work in another direction. Mr. Paton laid [illegible] education of the "bottom dog"; I [illegible] sure that it is good for the man or his employer, either from a moral standpoint or from the standpoint of obtaining the best results to the man or his employer. In the discusssion to-night it would appear as if we were only [illegible] college first and workshop last, ot[illegible] first, workshop next, and a further college course to complete their education. In central stations, however, and also I am sure in the majority of other works, we have to [illegible] youths are drafted in with no engineering experience, the [illegible] No doubt many members will remember the case of the man who in the course of his duties had to attend to a piece of machinery which was not running very well. He [illegible]

the machine and to his reputation as an engineer. Such instances could be multiplied, and they show the futility of the average engineering education obtained in central stations, where there happens to be no definite system of training. I should be glad to hear that others were giving this phase of the question more attention with the idea of evolving some general system for remedying such a state of things. With regard to evening classes, although as we have heard to-night there is a large percentage of youths who begin and do not follow up these classes, the system is generally productive of nothing but good, and it may be, and probably is a fact, that the large percentage shown of those who do not follow up the classes is due to causes over which the students themselves may have no control, such as the hours of labour, working over-time, lack of facilities, and so on. If there is one feature of education which we ought to persevere in, in my opinion it is in connection with providing facilities outside the working hours. It may confidently be asserted that men who are willing to attend classes after working hours in their own time, and who have the ability to persevere in such courses, are the most likely to become men of character and to achieve success.

Mr. Lord. Mr. J. W. Lord: Manchester at all events is taking some new step towards dealing with a part of the question. We have opened at Newton Heath a Junior Technical School to provide for boys of 13 or 14 who intend to enter some branch of the engineering trade. After completing the school course they would enter works for artisan training, but there is nothing to prevent them from rising to the class which the author has designated the "technical class." It is not a trade school in the sense in which the author uses the term; we shall have to call it, I think, a junior technical school. The difficulty of establishing trade schools is rather greater than some people seem to think. In Newton Heath, for example, we have a large railway carriage building works, a structural steel works, two or three electrical works, gas-plant works, a large general engineering works, textile machine works, and so on. It would not be possible in a district like that to run anything of the nature of a trade school; the school we can run must aim at fundamental principles—to use the term employed in the course of the discussion. The boys will learn practical mathematics, geometry, the principles of machine drawing, workshop practice—in fact everything that will help them to join some branch of the engineering trade. If more of these schools could be started I am quite sure we should get the right type of boy—the boy who would follow up engineering in after life. There are sometimes difficulties, but by personal examination—by seeing the boy and ascertaining what he thinks about it—the right type can be secured. This year we have started with 40 boys; when the school is fully established probably a hundred will be in attendance at any one time, taking some part of the two years' course, and after that they must go in for some branch of engineering. Several speakers have already pointed out how difficult it is for a boy to do good work in the evening school after a full day's labour. If the two years' course put him in a better position to take advantage of the evening classes it would be time well spent. After a day course extending over two years his evening work would naturally commence at a more advanced stage than would otherwise have been the case.

Mr. Paul. Mr. R. W. Paul (*communicated*): The necessity for the better trade instruction of electrical craftsmen has long been felt, and is emphasized by the present crisis; a good deal of the delay in supplying the needs of our fighting forces might have been obviated if such instruction had been systematically adopted in years past. Even in normal times there is no longer an adequate supply of all-round mechanics, like those of 25 years ago. This may be attributed to years of neglect on the part of some employers to afford thorough trade training to their younger employees. Any person responsible for engaging mechanics for highly skilled work must be impressed with the limited trade knowledge and abilities of the majority of applicants; on new and unaccustomed work expensive mistakes and wrong methods cause much economic waste. I believe that the same difficulty is felt in other countries, to a varying extent. Generally the best craftsmen and most successful leaders have learned their business in small shops, where adaptability and all-round skill are required. Such men are of great use to the larger concerns, and it is an encouraging sign that the British Westinghouse Company is setting a splendid example to those firms who have not hitherto taken their full share in the training of the workers on whom their success largely depends. The effort and expense, however, should be equitably distributed among all the firms of any given trade, since the benefits accrue to all alike. The initiative must come from the employers, as it did in earlier ages, but the co-operation of the educational authorities and trade unions might reasonably be expected. The latter might assist the movement by instructing ex-apprentices to prefer employment in those shops where the apprentices are properly instructed. I think that every practical man will admit that apprenticeship is necessary for the craftsman, as distinguished from the operator or machine minder, and that adequate trade instruction cannot be imparted by a busy foreman in a more or less noisy shop; it remains for the manufacturers in each branch to decide how the shop work can best be supplemented. I agree with the author that the functions of technical colleges and evening institutes, as at present constituted in England, bear little relation to the training of craftsmen. Since the author has referred to my own attempts, I may state, briefly, that my apprentices are divided into two classes according to ability; each apprentice spends the last two working hours of each day, except Saturday, in classwork. Elementary physics, mathematics, and trade drawing are taught by qualified teachers supplied by the Middlesex County Council, and these classes are held in school premises close to the works, the teachers visiting the shops occasionally in order to keep in touch with the practical side of the training. A shop has been equipped for instructional purposes in the works, and demonstrations of materials, machines, methods, and tools are given once a week by one of the foremen; on other afternoons specific operations are carried out by the apprentices, who receive individual attention. No saleable articles are made, nor is it intended to make instruments complete throughout, but the work consists of graduated exercises, commencing, for example, with the filing of a true cube from a cylinder. It is intended, later on, to construct simple, but accurate, tools and models for use in the laboratory classes; these classes are also held at the works by one of the staff, the number

[illegible]

[illegible] received the attention that it deserves from technically-[illegible] not drawn the attention of their students to this branch of [illegible] tice at the time he enters a works is attracted to the more purely design side. A great deal could undoubtedly be done to remedy this if the various colleges could arrange to include in their syllabus lectures on works organization, etc., as suggested by the author. For success on either the commercial or design side of engineering special abilities and characteristics are required, in addition to a thorough knowledge of the technical fundamentals. On the works side of manufacturing engineering this is of greater importance than on the other sides mentioned, as the human element is here more predominant. Take, for example, the case of shop engineers, referred to several times by the author. Their duties include the supervision of all new designs which go into the shop, the working-out of the most economic and quickest methods of manufacture, the reduction, utilization, and recovery of "scrap," the direction of the use of the most suitable materials in the articles manufactured, and the investigation and elimination of faults in the finished apparatus. In this field of work, perhaps more than in any other, there is unlimited scope for the application of scientific principles [illegible] this kind requires a broad scientific training, a knowledge of works organization, a knowledge of the properties and relative prices of all the materials employed, a capacity to [illegible] ledge of the life of the worker, both inside and outside the factory. This latter knowledge is necessary in order that [illegible] the engineer's. Referring to the five methods of training mentioned by the author, from my own experience I consider the second to be the best, provided the first period [illegible]

[illegible] the ad[illegible] Mr. [illegible] the [illegible] trouble, and apply the remedy quickly. In this age of [illegible] that reasoning power and initiative [illegible] in the quality of the product. In the case of an [illegible] winder apprentice the problem is rather difficult, as [illegible] principles of the relation of electricity and magnetism are [illegible] reasons for the different tests. The foremen of these departments find that the product bears the stamp of this intelligence. Attention to detail is specially emphasized. With apprentice draughtsmen shop-training is essential in order to obtain the best results. This training enables the [illegible] the common-sense simplicity of his drawings. A great advantage in the apprentice school is the close touch between the management and the boys. The different characters and temperaments of the boys are noted, and these will eventually decide the positions that they will hold.

[illegible]

Mr. N. necessary for all works not only to have men who have been trained in the particular machine practice in which they are employed, but also that they should have a good idea of the fundamentals in the particular work that they turn out and the materials used therein. I quite agree with the author that it is necessary for close co-operation between the masters of schools in engineering districts and the engineering firms. In the first place, I think very fruitful results could be obtained by providing at these schools a particular class to be known as a "Technical Form," in which boys who desire to enter the engineering trade are particularly instructed in such elementary knowledge as would be useful to them in their future work. I know that this particular arrangement produced very excellent results in the school that I attended. In this school there were two Sixth Forms—one being known as the Technical Sixth and the other as the Classical Sixth. Those boys who intended entering such professions as the Church, Law, or Medicine would enter the Classical Sixth, and those who intended entering Engineering and allied professions entered the Technical Sixth. I cannot see any reason why this scheme cannot be adopted in Board or Council Schools for the sake of those who intend actually to work with their hands and machine tools all their lives. The arrangement has also other great possibilities, in so far that at an early stage in a boy's life it gives an indication as to whether he will be suited for the particular class of work that he proposes (or his parents propose for him) to enter. If this arrangement were carried out it would be possible for masters of schools in the districts in which engineering works exist to keep in close touch with the heads of these firms, and to recommend from time to time various boys who in their opinion are suited for the production of skilled workmen. With regard to the question of apprentices, I agree with the author that the proper place for apprentice schools is in the works—in the first place, because, as the author implies, it gives the works' officials an opportunity of getting into touch with the boys individually, and of being able to pick out those who are particularly brilliant or suitable for advancement. Further, there are the particular advantages that will accrue by having instructors or lecturers actually out of the works who are able to give boys instruction in the very latest practice and point out to them the difficulties that have arisen previously, *i.e.* have necessitated changes in certain works' practices. This is not possible in the case of what one might term junior technical schools, as the masters would not have the same opportunity of keeping up to date as the foremen of large works. With regard to the smaller works, the only remedy that I could suggest in this particular case is that a number of small works should combine together to give apprentices the training that is deemed necessary. With regard to the actual early practical training, I am personally in agreement with the special apprentices' workshop, in which the boy is taught to use a particular tool—including speeds and feeds—for different materials and conditions of work; the use of lubricants for different materials, etc. Then the boy could be drafted into the works to gain actual experience under commercial conditions of the particular tool in which he has been instructed. I favour this scheme because in an engineering works of a modern type the foremen's hands are so full with the running of their departments that it is practically impossible for them to give a lad the detailed instruction which is necessary (and which he could get from the afore-mentioned class) in the operation of machine tools. With regard to the vocational instruction, I feel that the author's remarks on page 568 are of great importance, as the ignorance that one finds when dealing with skilled men to-day is astonishing, in the knowledge of materials that they are working with, and what they are to be used for on completion. I also consider that it is very important that the value of the materials which he is working with, and the importance of avoiding waste of time, should be impressed upon the boy early in his career, at the same time pointing out to him that all machines—whether running or standing—are worth a certain amount of money per hour. There is one point in the paper in which I do not agree with the author's remarks, *i.e.* that for works to rely for the recruiting of their apprentices from other works is not a good plan. I should say that it was a good plan for those works that have no trade schools to recruit men from such works as those of the British Westinghouse Company that have trade schools; and I am afraid, until it becomes a universal practice for works to have trade schools of their own, that those works who have not trade schools will always try to recruit men from works in which boys are instructed in trade schools. With this I will conclude my remarks on the training of so-called non-technical men, and I again add that I consider this side of the paper to be by far the most important, as it is from this side that we rely for the actual production of work; and in this country very little has been done on the lines of the author's suggestion in spite of its importance.

Passing on to the technical side, I am very pleased to note that the author includes leading foremen or inspectors in this section. In my past experience in dealing with foremen, I find there are very few that are able to criticize the work which they are turning out from any point of view except from that of general finish and accuracy of machining, whereas, particularly in electrical engineering work, there is an immense number of other details that require close inspection and investigation, which are very often overlooked, and which are not found out until the machine gets on to the test bed, or even out of the works and into the customer's hands. Personally, I consider it would be well to divide technical employment into two classes: one to include departmental managers, designers, and testers; the other, leading foremen, assistants of inspection, and draughtsmen. I will deal with the second section first.

Leading foremen and inspectors.—With regard to the training of men for this particular class of work, I think these should be drawn from the more brilliant section of the non-technical section; for there is not the slightest doubt that these men should have a good and sound knowledge of workshop practice, as of course a foreman must be able to criticize methods of machining and the speeds and feeds of machine tools. In addition, he should have such theoretical knowledge as to be able to detect such mistakes as one I noticed in the shop only the other day, viz. a strap connection between the brush-holder arms on a large continuous-current motor being of sufficient size to carry about 200 amperes, whereas the cable connector which took the current away from this strap was only sufficient

[illegible] positions to fill in [illegible] man to [illegible]

[illegible] non-technical trade school the most brilliant [illegible] these men have to be recruited— [illegible] age, before they are able to earn sufficient to keep them- [illegible] the better boys to a technical [illegible] restriction, although it may not of necessity remove it entirely. Further, there are, of course, a number of [illegible]

[illegible] iron and [illegible] to take [illegible]

shop practice; technical training on which at least two- [illegible] operations in the manufacture of electrical [illegible] in the purely designing [illegible]

Mr. Nelson be allotted to lectures on works organization, estimating, costing, etc. Having completed this last course of training the man is then able to decide for himself whether he will proceed to the shops side or the engineering side, and would be well-equipped to proceed to either. I should therefore suggest that it would be an excellent plan for a close co-operation between the technical colleges and large works to attain this end, as by this co-operation only can the above be possible, *i.e.* for the technical college to refer a proposed pupil to the manufacturing concern, or vice versa; and I agree entirely with the author that the works should not, if they wish to get the best of men, charge a premium. To all manufacturers this question of first, improving the training of the non-technical section, and secondly what I call Class 2 of the technical section, is one of the utmost importance; and I feel that there is not the least doubt that one of the chief reasons of Germany's progress as a commercial nation is due to the fact that it has realized that the training of the kind suggested by the author for all trades' apprentices is necessary to obtain the best results.

Mr. Pearce. Mr. J. G. PEARCE (*communicated*): With reference to Mr. Paton's remarks regarding the lack of interest that boys betray in their work owing to their ignorance of the part which their work plays in the general scheme, the apprentice school by arousing interest has a distinct advantage. Insulating material, for instance, may suffer considerably in the shops by careless handling if an apprentice is ignorant of the nature and function of that material. The need for this wider knowledge is so clearly recognized in Germany that apprentices of one trade are allowed to work for short periods in shops where another trade is carried on. Thus pattern-makers are allowed to work for a time in the foundry, and vice versa. Even machinists may take a six months' foundry course. Trade conditions in England seldom permit of this interchange, but an excellent practical idea of the functions of the various shops and of the processes which go on in them can be imparted in the trade school. The widespread adoption, both in America and on the Continent, of the training shop for the trade instruction of apprentices shows clearly that engineers recognize the impossibility of teaching trades within the walls of a classroom. But the training shop frequently fails to justify expectations, for these reasons: (1) Lack of shop discipline and the stringent commercial conditions under which shop work is done. (2) Lack of relationship between work done and wages received. (3) Extreme difficulty in obtaining an instructor who understands the art of teaching and who is thoroughly in touch with the trade. This could scarcely fail to be otherwise, since no provision for the training of such teachers exists. The advantages of collective teaching obviously centre round the uniformity of tuition and a proper correlation of practice and theory. On the other hand, the routine work of the shops does not afford a good training for an apprentice, because the foreman is generally too busy to attend to matters other than production even if he were a most suitable man for supervising such training, which is seldom the case. Further, the apprentice does not receive work in an increasing order of difficulty, and thus the value of graduated instruction is lost by violation of an elementary principle of teaching which demands that instruction should proceed from the known to the unknown and from Mr. Pearce. the simple to the complex. A compromise may be arrived at in the segregation of a special bench, machine, or group of machines in a shop for the use of apprentices. Thus, although this portion of the shop would remain productive, the boys would be gathered together in such a way that supervision would be easy and their progress could be carefully watched. They might be put in charge of an older apprentice who would be made responsible for the work done on the bench and for the teaching of the trade processes to the boys. It might further be possible for the newer type of shop engineer forecasted by the author to supervise all the apprentice groups in those departments relating to a clearly defined trade. Under these conditions, an apprentice working for periods of three months alternately in the special bench and in the general part of the shop, would get a much more efficient training than is obtained under the present much more haphazard system. Professor Walker has pointed out the perseverance necessary to complete a five years' course of evening-school study. In future, it would probably be found desirable to offer young men who wish to take such a course facilities for doing so during the daytime, allowing them to take a full university course. In this case the technical school would fulfil its proper function as a school for artisan students, with post-graduate courses for technically trained men. This is exactly the reverse of conditions obtaining at present, in which the large majority of students are attempting to get a technical education by part-time instruction. A comparison of the pass lists published for the first year and fifth year courses clearly shows, as the author points out, that the rate of mortality is high. Attention is only just beginning to be paid to the special needs of artisan students. In some parts of the country schools are being developed which receive employees of industrial firms for a few hours each week. These enable apprentices to avoid the strain which invariably follows the attempt to take evening-school work after the work of the day is completed, but it is doubtful whether this type of school has any advantage over the type in operation at the British Westinghouse works, the advantages of which the author has pointed out. But perhaps the strongest reason for preferring the company-operated school, or in the case of small employers, such a school run on a co-operative basis, is the fatal tendency of the technical school to allow its instruction to remain academic. Teachers frequently fail to emphasize the feature which makes even the most indifferent apprentice interested in the school work, that is the application of the scientific principles to the everyday work which has to be done. This would suggest the necessity for the training of a new type of teacher, who, in addition to possessing skill in imparting knowledge, shall be a craftsman who understands trade technicalities. It is invaluable for a firm to be able to plan its own instruction to meet its own special needs, to develop a lecturing staff in close touch with the needs of the trade and the industry, and to be free from grant-earning considerations. Firms who send apprentices to these day technical schools are in danger of encouraging the perpetuation of a system which has radically failed to train the artisan, a failure which is responsible for the introduction of the Westinghouse system.

Mr. A. P. M. Fleming (in reply): My remarks [illegible] instruction, but have [illegible] employment.

I am glad to note from Professor Marchant's remarks that efforts are made at Liverpool University to weed out during their college course those students who are likely to prove unfit for an engineering career. Such efforts, if made collectively [illegible] would do much to prevent overloading the profession with unqualified men. With regard to the importance that Professor Marchant attaches to research work, I think that this is excellent as long as the intention is to develop the student and not to [illegible] him for a special investigation which will be of little or no use to him in his future career, and which could be done probably more effectively by a man who has had practical experience.

With regard to the employment of technically-educated men on the works side of a manufacturing organization, I fully agree with Mr. Mensforth as to the scope and opportunities that this side affords. His remarks regarding the development of powers of observation and of capacity for successfully handling men particularly apply to the works side, although also of considerable importance in every other branch of engineering.

Mr. Paton's remarks, from the schoolmaster's point of view, are extremely interesting. As to the business of discovering the right kind of boys who should enter engineering, this is a matter of fundamental interest, and [illegible] can do a very great amount of good. The problem is a psychological one which has not heretofore received the careful consideration that its importance warrants. I fully endorse his views regarding the need for democratizing the profession and of fostering the "upward mobility" to which he refers. It is economically important to develop to the utmost the capacity of every youth.

Mr. Paton's reference to the class of youth who, on account of the character of his work is looked upon, and [illegible] such a lad receives should be directed to bring about a feeling of pride of achievement in workmanship which would serve to eliminate the ill effects of monotony and [illegible] contentment. As to the [illegible]

[illegible]

With regard to the [illegible] solely to the sequence which is best suited for training for the commercial side. [illegible] two" applies not only when the engineer is engaged [illegible] engineer should possess commercial instinct.

Mr. Thomas says [illegible] technical or non-technical employment—has to perform. [illegible] schools for the purpose of trade training, are pre-eminently suitable. That there is an awakening to the need of some [illegible] sideration.

Dr. Worrall considers that schools attached to works [illegible] annulled. His experience in regard to a low standard of workmanship is an unhappy one, and it is to raise this standard by the proper education and training of the [illegible] to restrict [illegible]

Mr. Fleming. educated men cannot be obtained solely on the test-plate or in the drawing office, but should comprise a very much wider scope of work in manufacturing departments, and some experience in the commercial and designing offices.

The remarks by Mr. Collinge regarding the training of young men engaged in central-station work are of considerable interest, but strictly speaking fall outside the scope of this paper. The difficulty of providing for the technical education by part-time study of youths working on shift is a very real one, and is worthy of the consideration of central-station authorities as a body.

Mr. Lord's remarks regarding the working of his school at Newton Heath are most interesting, and the progress of this—the first junior technical school in the district—will be followed with close attention by engineering employers. It will be particularly interesting to see what kind of employment the youths who attend this school ultimately follow and what rank they attain. From the experience of other schools of this kind there appears to be some likelihood of attention being directed largely to providing a course of training suitable for those youths who will ultimately rise to positions above that of the bench, and while there is ample scope for such, there is also a very crying need for training suited specially to the workman. While appreciating the difficulties of establishing trade schools, due to the variety of trades to be satisfied, the problem does not appear to be insurmountable, as shown by what has been accomplished in this respect on the Continent.

Mr. Paul, from his experience in conducting a training school in connection with his own works, calls attention to a very important feature of such a method of training, namely, the feeling of comradeship and healthy rivalry developed between apprentices of the same works striving for a common end. The introduction of this spirit of competition is an invaluable feature of the apprentice school. I think most employers who have undertaken educational work will agree with him that the expenses thereby involved should not fall on individual firms. There are not wanting signs of considerable development in the vocational education of youths, and it is to be hoped, when those firms who are now doing pioneer work in this direction have provided sufficient experience for the work to be carried out on a wider scale, that some national scheme can be evolved for dealing with the problem. From a personal visit that I was privileged to make to Mr. Paul's training school, I am convinced that the results which he is obtaining will be highly beneficial to his branch of the industry.

Mr. Flight emphasizes the need for technically-trained men on the manufacturing side of engineering, and outlines fully the wide scope that this branch affords. I am fully in agreement with his remarks. The relative sequence of college and works training, as I have already noted, is largely a matter of opinion and individual requirements, and I think it is impossible to lay down a ruling which satisfies every case.

Mr. Howarth points to the value of shop experience in a draughtsman's training. This is an important matter, particularly in electrical work, where one often finds many young men who seek to become draughtsmen without undergoing any practical workshop training. His views coincide with the method of training suggested in the paper.

Mr. Nelson recommends that in the council schools those boys intending to follow the engineering trades should be segregated, and should receive special instruction just prior to their leaving school. No doubt much would be gained from this if the educational authorities could see their way to provide such instruction. In any case, I think much good would result if schoolmasters would make themselves conversant with engineering requirements in their district, and thus be in a better position to direct to the engineering trades the most suitable youths. With regard to the use of a special apprentice workshop, this offers advantages where only one, or a very limited number of trades only have to be dealt with. In a large electrical works, however, embracing possibly a dozen trades, the difficulty of providing a special training shop becomes evident. I fully agree with his remarks that youths should be made to appreciate the various items that make up the cost of the apparatus they produce, and particularly also the importance of avoiding waste of materials, time, and effort.

Mr. Pearce points out the need for apprentices appreciating the function of their work in the whole sequence of operations in manufacture, and it is in the apprentice school that such information can be most successfully imparted. His suggestion of setting apart a small portion of each shop or department for the manual training of apprentices, under the charge of an advanced apprentice or shop engineer, appears to be excellent as a substitute for the separate training shop and would obviate many of the disadvantages of the latter. In the trade instruction of apprentices, the importance of the teacher being fully experienced in the requirements of the trade cannot be over-emphasized, and in this respect, as Mr. Pearce points out, it is invaluable for a firm undertaking educational work to be able to train teachers from its own staff.

I agree with Professor Walker that young men who consistently follow a five years' course of evening technical instruction show themselves to possess excellent characteristics, and it is unfortunate that it is impossible to devote the facilities available solely for the benefit of such students. The line of demarcation between the requirements of the artisan and those of the youth who has the ability to rise to technical employment is not clearly enough drawn, and no doubt a great deal of the overload existing in evening classes could be relieved by diverting a large proportion of the students into trade classes. As he points out, the provision of facilities for carrying out a national scheme of artisan training would increase enormously the efficiency of the workman. Such a scheme would require close co-operation between employers and educational authorities, but its organization appears to present no insurmountable difficulties.

THE INHERENT REGULATION OF SYNCHRONOUS ALTERNATING-CURRENT GENERATORS

By Alfred Still, Member

[illegible]

[illegible] al effect of the armature current. [illegible] current.

[illegible] This is convenient, and to some extent [illegible] of so-called equivalent sine wave- [illegible] wave shapes, thus eliminating the less- [illegible] ects caused by cross-magnetization and [illegible]

[illegible]

Fig. 1

[illegible] tion when the field excitation [illegible] is therefore the [illegible] by the [illegible]

[illegible]

Factors Influencing the Inherent Regulation of Alternators.

By enumerating all the factors which influence the terminal voltage of a generator driven at constant speed with constant field excitation, it will be possible to judge how nearly the methods about to be considered approximate to the ideal solution of the problem. These factors are :—

(*a*) The total or resultant flux actually cut by the armature windings (this involves the flux linkages producing armature reactance).

(*b*) The ohmic resistance of the armature windings.

(*c*) The alteration in wave shape of the generated electromotive force, due to changes in air-gap flux distribution. This means that the measured terminal voltage is not necessarily proportional to the amount of flux cut by the conductors, because this determines the average value of the developed voltage, while the form of the E.M.F. wave determines the relation between the mean value and the virtual or R.M.S. value.

By far the most important items are included under (*a*), and it will be well to consider exactly how the resultant flux cut by the armature windings varies when load is put on the machine.

Considering first the flux cut by the active belt of conductors under the pole face, this is not usually the same under load conditions as on open circuit (the field excitation remaining constant), for the following reasons. The current in the armature windings produces a magnetizing effect which, together with the field-pole magnetomotive force, determines the resultant magnetomotive force and the actual distribution of the flux in the air-gap. When the power factor of the load is approximately unity, the armature current produces a cross-magnetization and a distortion of the resultant field, accompanied usually by a reduction of the total flux owing to increased flux density in the armature teeth where the air-gap density is greatest. This effect is, however, less marked in alternating-current than in continuous-current generators, because in the former the tooth density is rarely so high as to approach saturation. On low power factor, with lagging current, the armature magnetomotive force tends to oppose the field magnetomotive force, and on zero power factor its effect is wholly demagnetizing, thus greatly reducing the resultant air-gap flux. With a leading current the well-known effect of an increased flux and a higher voltage is obtained. The effect known as armature reaction, as distinguished from armature

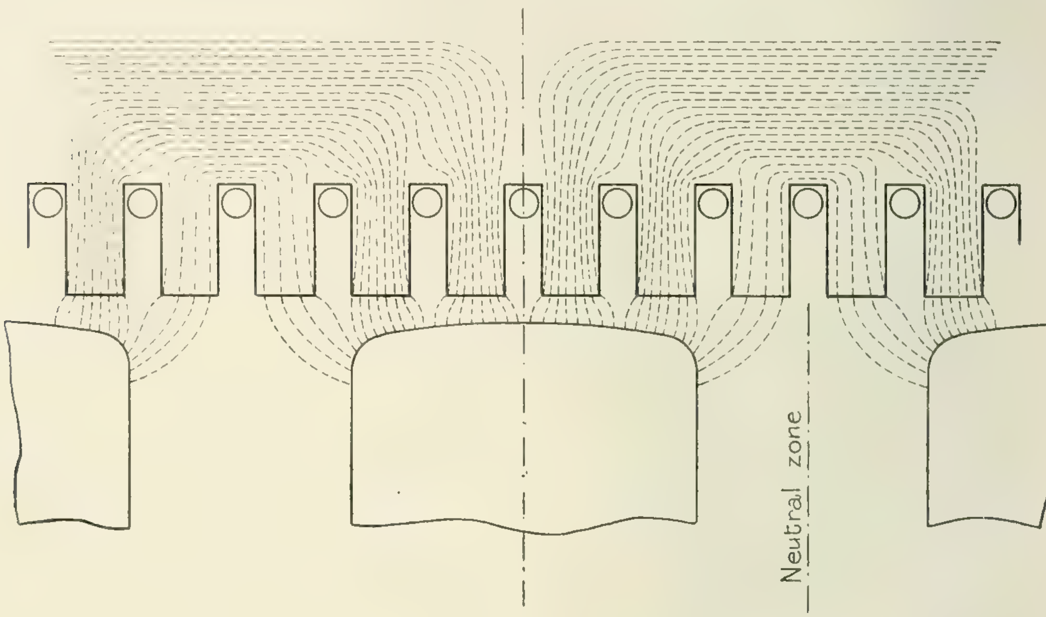

Fig. 2.

reactance, is therefore dependent not only on the amount of the armature current but also largely upon the power factor.

Apart from the action of the armature winding as a whole, causing a reduction of the total flux crossing the air-gap from pole face to armature teeth, it is necessary to consider the effect of the individual conductors which, by producing a leakage of flux in the slots themselves, still further reduces the useful flux when current is taken from the machine. The whole of the flux entering the tops of the teeth is not cut by the conductors buried in the slots, and the voltage actually developed in the "active" portion of the armature windings will be reduced in proportion to the amount of flux which, instead of entering the armature core, is diverted from tooth to tooth. This loss of voltage is usually attributed to the reactance of the embedded portion of the windings, and is referred to as a reactance voltage. This term, however, although very convenient, is liable to lead to confusion when an attempt is made to realize the physical meaning of armature reactance. It suggests that a certain electromotive force is generated in the conductors, thus causing a flow of current which in turn produces the

flux of self-induction and a reactive electromotive force. [illegible] the actual amount of flux in the armature core; [illegible] little practical interest, yet tending to obscure the issue when considering the problem of regulation.

The effect of the current in the [illegible] conductors will be understood by comparing Figs. 4 and 5, where the dotted lines indicate roughly the paths taken by the [illegible] flux under open-circuit conditions (Fig. 4) and under load conditions (Fig. 5). [illegible]

tion. The [illegible] calculation of this electromotive force will be considered later. [illegible]

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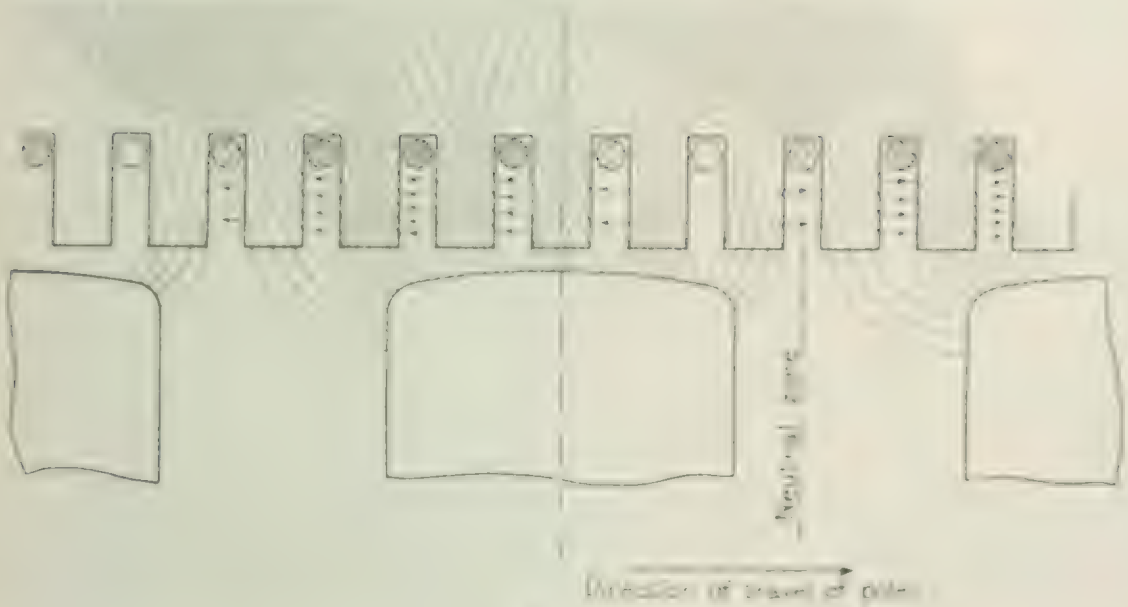


Fig. [illegible]

portion of the total flux leaving the pole-shoe which crosses the air gap but does not enter the armature core below the teeth, disposes of the difficulties encountered by many engineers (including some authors of text books) when faced with the necessity of calculating the end inductance. It is unnecessary to consider the leakage flux in the slots under the pole face, but it is important to know the amount of flux in the neutral zone* which passes from tooth to tooth and generates no electromotive force in the conductors. If this leakage flux (in the neutral zone) were actually cut by the conductors, it would generate a component of electromotive force lagging one quarter period behind the main component (on the assumption of sine-wave forms) and it can therefore conveniently be represented in vector diagrams as if it were an electromotive force of self-induc-

* [illegible]

armature windings, and is negligible at open circuit. For a given output and power factor, the end flux in a polyphase generator is fixed in position relatively to the field poles, [illegible] The maximum value of the armature magnetomotive force occurs at the point where the current in the conductors is zero, and on the assumption of a sinusoidal flux distribution, the electromotive force generated by the cutting of these end fluxes may be represented correctly as a vector drawn 90° behind the current vector. It is therefore correct to consider this E.M.F. component as a reactive voltage such as would be obtained by connecting a choking coil in series with the "active" portion of the armature windings; and if the inductance [illegible] of the end windings is known, and a sinusoidal flux distribution assumed, the electromotive forces developed by the cutting of the end fluxes under load conditions is given by the well-known expression [illegible], where I is the virtual value of the current in the armature windings, and f is the frequency.

Approximate Method of Predetermining Regulation.

If all the alternating quantities are simple harmonic functions, the regulation can be calculated by using vector diagrams. Let curve A of Fig. 4 represent the open-circuit characteristic of the machine; it can be drawn fairly accurately from design data after the whole magnetic circuit has been designed, since the flux density in the various parts of the magnetic circuit can be calculated and the necessary total magnetizing ampere-turns estimated, excepting that the flux leakage from pole to pole is not very easily estimated in new types of machines. It is

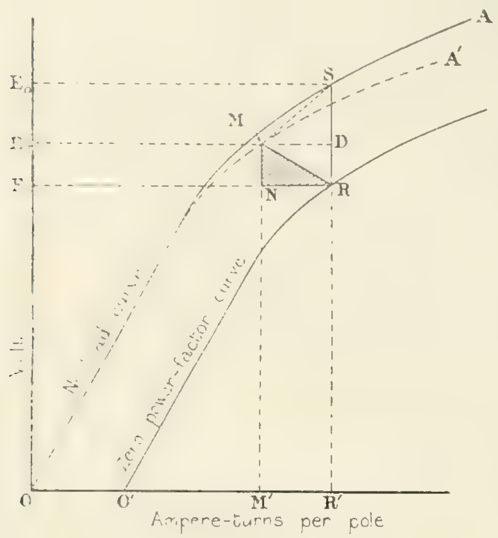


Fig. 4.

assumed that the quantities required for the construction of the vector diagrams are known; but a means of estimating the probable quantitative effects of the slot and end fluxes will be considered later.

Load Saturation-curve for Zero Power Factor.

In practice, any power factor below 20 per cent is usually considered to be equivalent to zero, so that the calculations can be checked when the machine is built by providing as a load for the generator a suitable number of induction motors running light. On these low power factors with lagging current the phase displacement of the armature current causes the armature magnetomotive force to be almost wholly demagnetizing, that is to say, it directly opposes the magnetomotive force due to the field windings, the distortional or cross-magnetizing effect being negligible. Its maximum value per pole is easily calculated, and its effect in reducing the flux in the air-gap is readily compensated (on zero power factor) by increasing the field excitation so that the resultant ampere-turns remain unchanged. This statement is not strictly correct because the increased ampere-turns on the field poles give rise to a greater leakage flux, and this alteration should not be overlooked, especially when working with high flux densities in the iron of the magnetic circuit. If the estimated leakage flux for a given developed voltage on open circuit is Φ_l maxwells, then, for the same voltage with full-load current on zero power factor, the leakage flux would be approximately $\Phi' = \Phi \left(\frac{M + SI}{M}\right)$ where M is the number of field ampere-turns on open circuit, and (M + S I) is the number of field ampere-turns with full-load current in the armature, the power factor being zero. The quantity S I is the demagnetizing ampere-turns per pole due to the armature current.

Knowing the increase of flux in pole and frame, the magnetomotive force required to overcome the increased reluctance of these parts can be calculated, and in this way the dotted curve A′ of Fig. 4 can be drawn. This is merely the open-circuit saturation curve corrected for increased leakage flux due to the additional field current required to balance the demagnetizing effect of a given armature current.

In the vector diagram Fig. 5, let O E_t represent the required terminal voltage if the machine is mesh connected, or the corresponding potential difference per phase winding if the machine is star connected. (In a 3-phase Y-connected generator O E_t would be $1/\sqrt{3}$ times the terminal voltage.) The vector O I, drawn 90° behind O E_t, is the armature current on zero power factor. The impedance-

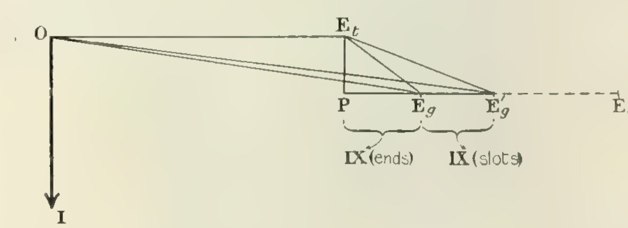


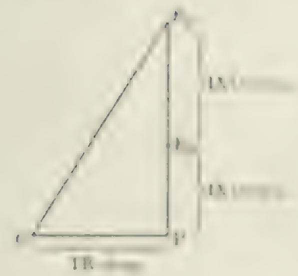
Fig. 5.

drop triangle is now constructed by drawing E_t P parallel to O I of such a length as to represent the I R drop per phase, and P E_g at right angles to O I to represent the reactive pressure drop per phase in the end connections. O E_g is therefore the voltage actually developed in the slot conductors because it contains the component P E_g to balance the voltage generated by the cutting of the end flux, and the component E_t P to overcome the ohmic resistance of the windings. Now produce P E_g to E_g' so that $E_g E_g'$ represents the voltage that would be developed by the slot flux if this were cut by the conductors. O E_g', which may be called the apparent developed voltage, is then the electromotive force that would have been developed in the armature windings if the slot flux had actually entered the core instead of being diverted from tooth to tooth by the action of the current in the conductors. It is therefore also a measure of the total flux passing through the air-gap into the armature teeth, and the magnetizing ampere-turns necessary to produce this flux would, on open circuit, actually develop this electromotive force in the armature. Thus when the resultant magnetomotive force in the magnetic circuit is such that E_g' volts would be developed on open circuit, the terminal voltage under the assumed load conditions would be E_t. It is usual, when the power factor is zero, to consider this loss of pressure as equal to the total reactive drop (E_g'P) because, owing to the relative smallness of P E_t and the

[illegible] reactance capable of producing the same total loss of pressure if the magnetomotive force of the armature had [illegible] to S R of Fig. 4, the vector diagram shows the difference [illegible] pressure O E_t under load conditions at zero power factor when the field excitation is maintained constant. The additional (fictitious) reactance drop E E_t' is correctly drawn at right angles to the current vector because on zero power factor the effect of the armature magnetomotive [illegible] thrown off, the balancing M.M.F. component on the field poles will generate the additional voltage in the phase O E. It should be realized that the fictitious reactance drop, $E_t E_t'$ of Fig. 5, cannot be predetermined until the whole [illegible] however, of the total difference of voltage depends on the slope of the line M S, and is thus some function of the [illegible]

[illegible]

[illegible]



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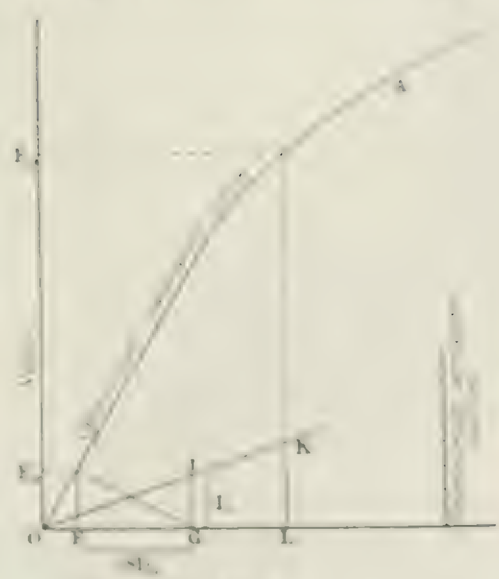


[illegible]

[illegible] the flux in the air-gap must be such that [illegible]

since the magnetomotive force of the armature windings will be almost wholly demagnetizing, it is correct to assume that the field excitation must be increased by an amount equal to the maximum armature ampere-turns per pole in order that the resultant excitation may be O F. Thus F G in Fig. 7 is made equal to the maximum armature ampere-turns,* and by drawing, to a suitable scale, the ordinate G J equal to the assumed armature current I_c, the point J on the short-circuit current curve is obtained. By repeating the construction for any other assumed value of the current it will be seen that so long as E_x' lies on the linear portion of the no-load characteristic, the relation between the short-circuit current and the field-pole excitation is also linear. When the field excitation is O L, giving a pressure O E_o on open circuit, the short-circuit current will be L K.

Regulation on any Power Factor.

Unless the effects of cross magnetization are taken into account, it is impossible to predetermine the regulation accurately when the power factor differs appreciably from zero, but by the intelligent use of vector quantities (involving as they do the assumption of simple harmonic curves) very satisfactory results can be obtained. The best method known to the author by which the load saturation-curve for any power factor may be drawn, without resorting to flux distribution and wave-shape analysis, is that given by Professor Alexander Gray.† A. E. Clayton ‡

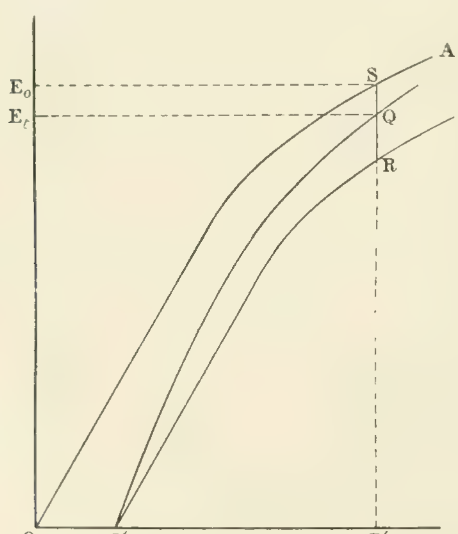


FIG. 8.

has also suggested a similar method. For example, let the external power factor be cos θ, and O R′ (Fig. 8) the constant field excitation which would, on open circuit, develop the pressure E_o represented by R′ S. The full-load-current zero-power-factor saturation-curve O′ R has been drawn as previously described. If then it is possible to determine the point Q on the full-load saturation curve for power factor cos θ, the required percentage regulation may be expressed as $100 \frac{QS}{QR'}$.

In Fig. 9 draw the right-angled triangle E_t P E_o such that P E_t represents the armature resistance drop per phase with full-load current, and E_o P the corresponding synchro-

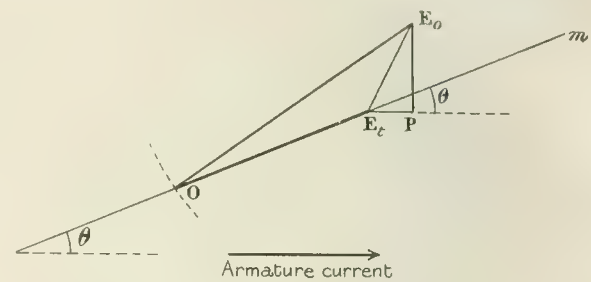


FIG. 9.

nous reactance drop, as given by S R in Fig. 8. From E_t draw the line $E_t m$ of indefinite length and so that $m E_t$ P is the required power-factor angle θ. From E_o as centre describe the arc of a circle of radius R′ S (Fig. 8) equal to the open-circuit voltage and cutting $m E_t$ produced at O. Then O E_t will be the required terminal voltage, which may be plotted as R′ Q in Fig. 8. This construction provides for the proper angle θ between terminal voltage and current; and in regard to the relation between the terminal voltage E_t and the open-circuit voltage E_o when load is thrown off, it will be seen that the total synchronous reactive drop has been used in the impedance triangle E_t P E_o of Fig. 9. This virtually assumes the demagnetizing and distortional effects of the armature current to be equivalent to a fictitious reactance capable of being treated vectorially like any other reactance, and of which the direct effect on regulation is proportional to the sine of the angle of lag—a not unreasonable assumption though scientifically inaccurate. This gives good results in machines of normal design. It is when departures are made from standard practice that such approximations are liable to be abused.

Calculation of Armature Inductance.

The flux cut by the conductors which project beyond the ends of the armature slots is very difficult to calculate, and empirical formulæ based on experimental data are generally used for predicting the probable value of the inductance of the armature end connections. In Fig. 10 let τ represent the pole-pitch of a 3-phase generator, and l' the average axial extension of the coils beyond the ends of the armature core.* If the total flux produced by the armature currents, in the space τ centimetres wide by l' centimetres deep as shown cross-hatched in Fig. 10, can be estimated, the voltage developed by the cutting of this flux can readily be calculated. Without attempting to go into the niceties of mathematical analysis—which would

* On the assumption of sine wave-form, the total armature ampere-turns per pole, due to the currents in all the conductors of a 3-phase machine, may be taken as

$$(S\,I)_a = \frac{3\,Z}{\pi\,p} \sqrt{2}\,I$$

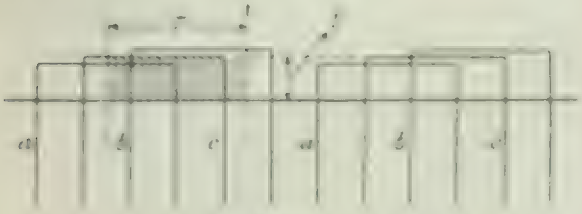
where Z is the number of conductors per phase, and p is the number of poles.

† A. GRAY. "Electrical machine design."

‡ *Electrician*, vol. 73, p. 90, 1914.

* The equivalent projection of a coil that is bent up to clear the coils of other phases might be considered equal to the projection of the same coil if flattened out.

[illegible]



[illegible]

[illegible]

$$\Phi = k\,T\,I\,l_e \left(\frac{6}{n_s + 5}\right) \log_{10} [illegible] \qquad (1)$$

where T = [illegible]

n_s = the number of slots per pole per phase ;

l' = [illegible] in centimetres ;

$l_e = (2\,\tau + 4\,l')$ = approximately the total length in centimetres per turn of wire in a coil, less the slot portion ;

I_c = the armature current per conductor (R.M.S. value) ;

k = constant, approximately unity, depending upon [illegible]

The quantities $6/(n_s + 5)$ and $\log (12\, n_s\, l')$ are factors [illegible] l' of the coils will influence the total flux to a greater extent than the end length τ which appears in the expression for [illegible]

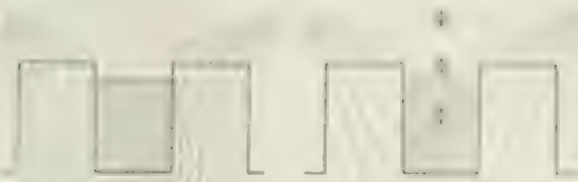
[illegible]

$$E_e = [illegible] \qquad (2)$$

[illegible]

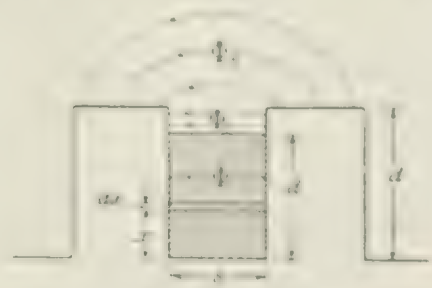
[illegible]

[illegible] Diagrams (A) and (B) in Fig. [illegible]



[illegible]

paths of the magnetic lines in the neutral zone, (A) when [illegible] conductors to be acting independently of the field magneto-motive force. [illegible]



[illegible]

sum of three component fluxes Φ_1 passing through the [illegible] cut by some of the conductors ; Φ_2 crossing the space [illegible]

[illegible]

loss of pressure. This flux may be calculated as follows: The amount of flux in the small strip dx deep (Fig. 12) of 1 cm. axial length, *i.e.* perpendicularly to the plane of the paper, is $d\Phi_1 = \text{M.M.F.} \times dP$, where dP is the permeance of the air path—the reluctance of any iron in the path of the lines being neglected. Whence

$$d\Phi_1 = (0{\cdot}4\,\pi\,T_s\,I_s)\,\frac{x}{d_1} \times \frac{dx}{S}$$

where T_s is the number of conductors per slot; I_s is the current per conductor in amperes; and the dimensions d_1 and S (see Fig. 12) are in centimetres. Since, however, this flux element (see Fig. 11, B) is cut by $T_s(d_1 - x)/d_1$ conductors, the loss of pressure is due to the fact that it is *not* cut by $T_s x/d_1$ conductors. The "equivalent" flux to cause the same loss of pressure would, if it did not link with any of the conductors, therefore be

$$d\Phi_{1\,(\text{equivalent})} = d\Phi_1 \times \frac{x}{d_1}$$

Thus
$$\Phi_{1\,(\text{equivalent})} = \frac{0{\cdot}4\,\pi\,T_s\,I_s}{d_1^2\,S}\int_0^{d_1} x^2\,dx$$

$$= \frac{0{\cdot}4\,\pi\,d_1}{3\,S}\,T_s\,I_s$$

The permeances of the air paths of the component fluxes Φ_2 and Φ_3 can be calculated fairly accurately. Let them be P_2 and P_3 respectively. Then, if l_a is the axial length of the armature core in centimetres, the total "equivalent" slot flux in the neutral zone is

$$\Phi_s = 0{\cdot}4\,\pi\,T_s\,I_s\,l_a\left(\frac{d_1}{3\,S} + P_2 + P_3\right) \quad . \quad . \quad . \quad . \quad (3)$$

If Φ_a is the flux per pole actually cut by the conductors, the total flux per pole in the air-gap under load conditions will be $\Phi_t = \Phi_a + 2\,\Phi_s$.

This total flux, if actually cut by the armature conductors, would generate the electromotive force referred to as the "apparent" developed voltage, and represented by $O\,E_g'$ in Fig. 5.

The flux $2\,\Phi_s$ maxwells is the portion of the total air-gap flux which, under load conditions, is no longer cut by the armature conductors. The average value of the voltage lost per phase winding is therefore

$$E_{(\text{average})} = \frac{2\,\Phi_s\,p\,N}{10^8 \times 60}\,(T_s\,n_s\,p)$$

or, since $N\,p = 120\,f$

$$E_{(\text{average})} = 4\,\Phi_s\,f\,(T_s\,n_s\,p)\,10^{-8}$$

Assuming the sinusoidal wave shape, it is necessary to multiply by $\frac{\pi}{2\sqrt{2}}$ to obtain the R.M.S. value. Thus

$$E_s = \frac{2\,\pi\,f\,\Phi_s\,T_s\,n_s\,p}{\sqrt{2} \times 10^8} \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

The slot flux in the neutral zone will be a maximum on zero power factor when the current I_s producing it is approximately equal to the maximum value of the armature current, or to $\sqrt{2}\,I_c$. Inserting this value of I_s in formula (3) and substituting in formula (4) we get

$$E_s = 2\,\pi\,f \times 0{\cdot}4\,\pi\,T_s^2\,n_s\,p\,l_a\left(\frac{d_1}{3\,S} + P_2 + P_3\right) \times 10^{-8} \quad . \quad (5)$$

This quantity is usually referred to as the reactance voltage drop per phase due to the slot inductance: it appears as the vector $E_s\,E_g'$ in Fig. 5.

Influence of Flux Distribution on Regulation.

So long as a sinusoidal air-gap flux-distribution can be assumed both on open circuit and under load conditions, the previously described methods of predetermining regulation are satisfactory: but in the case of new or abnormal designs of machines, correct results can only be obtained by taking into account the alteration in the amount of the useful flux due to cross-magnetization and the changes in the E.M.F. wave-shapes due to flux distortion. An attempt will be made to outline as briefly as possible a method of study which, although it has been elaborated by the present author, is not essentially new; indeed, it is probably used in a modified form by some practical designers when aiming at a closer degree of accuracy than can be expected from methods based on the usual sine-wave assumptions.

The method about to be described is embodied in the course of Electrical Design taken by the Senior Students in the School of Electrical Engineering of Purdue University, La Fayette, U.S.A. It is based on the fact that for salient-pole machines approximately correct flux-distribution curves can be drawn when the width and shape of the pole-shoe have been decided upon; and for high-speed generators with air-gap of constant length when the disposition and windings of the slots in the rotor have been determined.* The actual plotting of these curves for different load conditions is somewhat tedious. The permeance between pole face and armature for various points on the armature periphery, and the resultant magnetomotive force tending to set up a flux of induction at each point must both be known. These are obtained by drawing two curves showing the M.M.F. distribution due to field ampere-turns only and due to armature currents only: the sum of corresponding ordinates of these two curves gives the required resultant magnetomotive force for any desired armature current and power factor.

It is then easy to derive the E.M.F. waves together with their R.M.S. values, and the problem of regulation may be summed up as follows: Given a definite field excitation, plot the open-circuit flux curve and obtain the R.M.S. value of the resulting electromotive force. Let this be E_o. Now draw the armature M.M.F. curve for a given current and power factor; combine this with the field M.M.F. curve used for obtaining E_o, and from the resulting M.M.F. curve the electromotive force developed under load conditions can be obtained by plotting the flux distribution curve. Let E_g' be the R.M.S. value of this voltage, the quantity previously referred to as the "apparent" developed electromotive force. Correcting for internal pressure losses, ohmic and reactive, a value is obtained for the terminal voltage E_t, and the corresponding regulation is $(E_o - E_t)/E_t$.

The actual working out of this problem is not quite so simple as this statement may suggest, the chief difficulty being that a knowledge of the external power-factor angle is insufficient to determine the exact position

* C. R. Moore. Air-gap flux distribution in direct-current machines. *Transactions of the American Institute of Electrical Engineers*, vol. 31, p. 509, 1912. Also L. D. Curtner. *Purdue Engineering Review*, May 1914.

of the armature M.M.F. curve relatively to the centre line of the pole. The position of this curve depends upon the internal power-factor angle and also upon the phase displacement of the generated electromotive force under load conditions, [illegible] of the resultant air-gap flux [illegible] distributed symmetrically about the centre line of the pole face.

Outline of Procedure in Calculating Regulation from Study of E.M.F. Waves.

In Fig. 13 let the curve F represent the distribution of magnetomotive force over the armature surface tending to send flux from pole to armature [illegible]. F should include the ampere-turns per pole required to overcome the reluctance of air-gap and teeth and those to send the

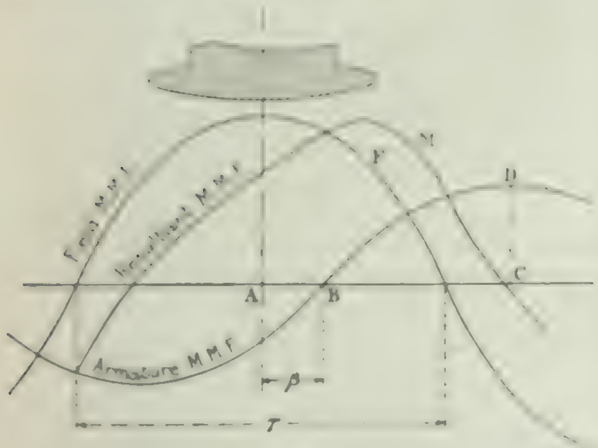


Fig. 13.

total flux (including leakage) through the remaining portions of the magnetic circuit. Let B D be the magnetomotive force due to armature current only. If the load current be sinusoidal (an almost essential assumption, since its exact shape cannot be predetermined), B D will also be a sine curve, the maximum ordinate C D of which will be displaced beyond the centre line of the pole by an amount depending upon the power factor of the load and the distortion of the resulting air-gap flux-distribution. This maximum value will occur where the current in the conductors is zero, and the maximum armature current will be carried by the conductor displaced exactly 90 electrical space-degrees from the point C. The point B is therefore the position on the armature surface, considered relatively to the poles, where the current is a maximum, the length A B or β, which depends largely on the power factor, being for the present assumed. Add the ordinates of curves F and D to get the curve M which gives the resultant magnetomotive force under the assumed conditions of load. Having calculated (by methods discussed elsewhere*) the permeance of the magnetic circuit for various points on the armature surface, the flux distribution curves A and B of Fig. 14

* [illegible]

can be plotted. The first, which represents open-circuit conditions, is plotted from the M.M.F. curve F, while curve B, showing the flux distribution under load, is derived from the M.M.F. curve M. The respective areas of these curves (which can be ascertained with a planimeter) are a measure of the total air-gap flux under the two conditions, and since the average value of the "apparent" developed voltage will be proportional to

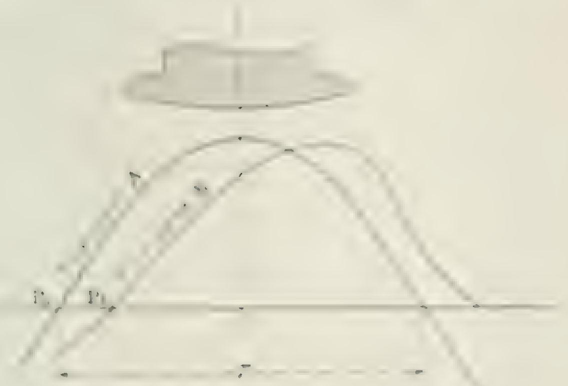


Fig. 14.

these areas, the regulation can be obtained, as a first approximation, by assuming that the E.M.F. waves are sine curves.

The correct solution of the problem involves the actual wave-shapes of the developed electromotive forces. Whatever may be the number and spacing of the slots on the armature surface, the actual E.M.F. wave shape can always be plotted in the manner indicated in Fig. 15, where the full curve may be any of the flux curves previously obtained, such as B in Fig. 14, the ordinates of which are a measure of the average flux density in the

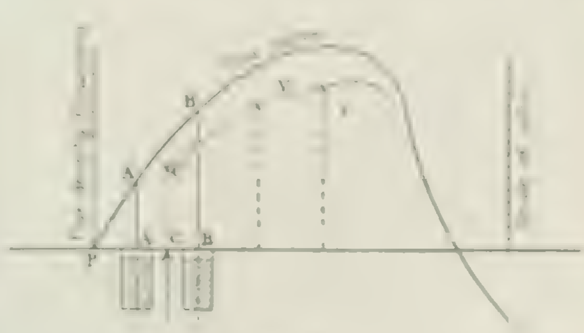


Fig. 15.

air space near the surface of the armature. Draw A and B properly spaced to represent the slots, *e.g.* two in this illustration, of one phase of the armature winding. At the instant when the centre line C of this phase winding occupies the position shown in Fig. 15, the conductors in slot A are moving in a field of density A A', while the conductors in slot B are cutting a field of density B B'.

These conductors are all in series, and the instantaneous value of the voltage per phase winding will be

$$e = \frac{B_a N \pi D l Z}{60 \times 10^8}$$

where B_a = average value of flux density, in gausses;

$= \frac{A A' + B B'}{2}$ in this instance;

N = revolutions per minute;

D = armature diameter in centimetres;

l = armature length (axial) in centimetres;

Z = total number of conductors in series per phase.

This value of e is plotted as C C′ to a suitable scale, and the process is repeated for other positions of the armature slots, thus producing the dotted curve V, representing the electromotive force that would be developed in the windings if all the flux in the air-gap were cut by the conductors in the slots. The electromotive force actually developed will depend—as previously explained—on the amount and distribution of the slot flux; and the wave shape of the voltage actually developed can be predetermined if desired; but as the correction can be made with sufficient accuracy by means of a final vector construction, a knowledge of what has been called the "apparent" developed voltage is alone necessary.

Having obtained a curve giving the successive instantaneous values of the electromotive force under load conditions, it is easy to derive its R.M.S. value. The most satisfactory way of obtaining this is to replot the curve on polar co-ordinate paper, and measure its area. The virtual value of the non-harmonic electromotive force is then given by

$$E_g' = \sqrt{\frac{\text{twice area of one lobe}}{\pi}}$$

The terminal voltage—which must be known before the regulation can be calculated—is most readily obtained by using vector diagrams; but this involves the substitution of "equivalent sine curves" for the irregular waves. The maximum value of a so-called equivalent sine wave is $\sqrt{2}$ times the R.M.S. value of the irregular wave; but its time-phase relatively to any defined instantaneous value of the irregular wave is not so easily determined. It can be obtained from the irregular curve when plotted to polar co-ordinates; but a preferable method for the purposes of explanation, although more tedious, consists in obtaining the average value of the true power and making the displacement between electromotive force and current vectors equal to $\cos^{-1}\left(\frac{\text{true power}}{\text{apparent power}}\right)$. The current wave (assumed to be a sine curve) from which the M.M.F. curve B D of Fig. 13 is derived would have its maximum value at the point B, displaced β electrical degrees beyond the centre, A, of the pole. The actual full-load E.M.F. wave, such as V of Fig. 15, can also be drawn in the correct position relatively to the centre line of the pole; and, by multiplying the corresponding instantaneous values of electromotive force and current, the power curve can be drawn and the average value of its ordinates calculated. The ratio of this quantity to the volt-amperes is equal to the cosine of the angle ψ' in Fig. 16. This vector diagram can be constructed as follows:—

Draw O E_o to represent the assumed open-circuit voltage corresponding to the given field excitation as used in deriving the M.M.F. curve, F, of Fig. 13. Make the angle E_o O I_c equal to β of Fig. 13. This is the estimated lag of current behind the open-circuit electromotive force. Draw O E_g' equal in length to the calculated R.M.S. value of the "apparent" developed voltage under load conditions, and so that $\psi' = \cos^{-1}\left(\frac{\text{watts}}{\text{volt-amperes}}\right)$, where the watts referred to are calculated by multiplying the corresponding instantaneous values of E_g' and I_c. From E_g' drop a perpendicular on to O I_c, and set off E_g' E_g and E_g P to represent the reactance drops in slots and end connections respectively, calculated as above. Draw P E_t parallel to O I_c to represent the resistance pressure-drop per phase, and join O E_g and O E_t. The regulation of the machine is then $\frac{O E_o - O E_t}{O E_t}$. This regulation may not correspond to the exact values of external power factor and terminal voltage assumed when estimating values for the open-circuit voltage E_o and the angle β; but, by using the vector construction on the assumption of sine waves throughout, a very close estimate of these quantities can be made. The important point in connection with this method of analysis is that the external power-factor angle θ and the terminal voltage E_t can be calculated for any value of the armature current I_c when the phase displacement of the latter relatively to the open-circuit voltage E_o is assumed.

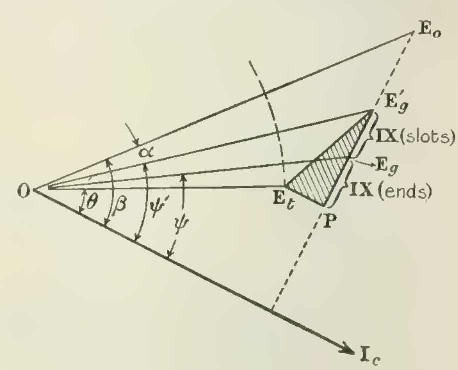


FIG. 16.

The meaning of the other quantities in Fig. 16 may be summed up as follows:—

The angle E_o O E_g', or α, is the phase difference between equivalent sine waves representing open-circuit voltage and "apparent" developed voltage under load conditions. It is the result of flux distortion due to the armature cross-magnetizing ampere-turns. The vector O E_g gives the R.M.S. value of the voltage per phase winding actually developed in the armature inductors by the cutting of the flux entering the armature core.

The angle E_g O I_c or ψ is the internal power-factor angle. The difference in length between O E_o and O E_g' is the voltage-drop due to armature demagnetization and distortion. The point E_o is shown in Fig. 16 on P E_g' produced, but it does not necessarily fall on this straight line, and so

[illegible]

THE DEVELOPMENT OF ELECTRIC POWER FOR INDUSTRIAL PURPOSES IN INDIA

By H. R. [illegible], Associate Member.

([illegible])

[illegible]

[illegible] view of the fact that in the two great industrial centres [illegible] plant in India.

It would appear, however, that with few exceptions British manufacturers of electrical machinery have in the [illegible] initial expense essential for systematically canvassing the country.

[illegible] the commercial side of engineering, or as a matter of fact [illegible] impossible to develop a remunerative market for any manufacture or to work up any business connection of value in any country without incurring a capital outlay. [illegible] commission basis, and almost without exception this method has proved unsatisfactory. In the majority of cases the agency firms in India have been purely com-[illegible]

[illegible] machinery quite [illegible] engineers to regard with keen disfavour electric plant for mill or factory working.

[illegible] arrangement, however, has also [illegible] factory, as a representative can only be in one [illegible] a time, with the result that as soon as any mill or factory has installed electric plant the engineer is off elsewhere [illegible] nurse carefully any new electric power [illegible] the first 18 months or two years, or as a [illegible]

[illegible] pective purchaser is whether the manufacturer is prepared to install and supervise for at least a few months the running of the plant it is proposed to install. [illegible] of the large industrial centres of India [illegible] by steam plant owing solely to the lack of qualified [illegible]

[illegible] individual attention which is really due to pioneering electrical scheme of any importance in India.

[illegible]

Time and again the author when calling in tenders for electrification schemes has had favourable competitive prices from British manufacturers at f.o.b. and c.i.f. rates. These unfortunately are quite useless for a country where the application of electricity for power purposes is, practically speaking, in its infancy. Almost without exception mill-owners will under no circumstances purchase electrical plant on such terms, nor will they assume the responsibility for the erection of their own plant; moreover, one is not justified in either asking or recommending them to do so. Even in such cases where commercial houses holding an electrical agency undertake erection, trouble ensues in nine cases out of ten, with the inevitable result that the electrical installation falls into disfavour.

There is no doubt whatever that the time has now come for British electrical manufacturers to realize that if they wish to the manufacturers. Fig. 1 shows clearly the relative increase of electrical imports since 1907, as against the decrease of steam plant importation over the same period.

Continental Competition.

It must be a matter of regret to us that during the last few years a very great proportion of the electrical plant installed in India, together with its component parts, viz. hydraulic and steam turbines, has been supplied from the Continent. Table 1 embodies the chief data of the five most important public electric supply undertakings in India, and from these statistics it will be observed that of 66,900 kw. of plant installed in these stations Switzerland has supplied 54,000 kw., England only 7,500 kw., and the United States 5,400 kw. of the prime-movers, whilst

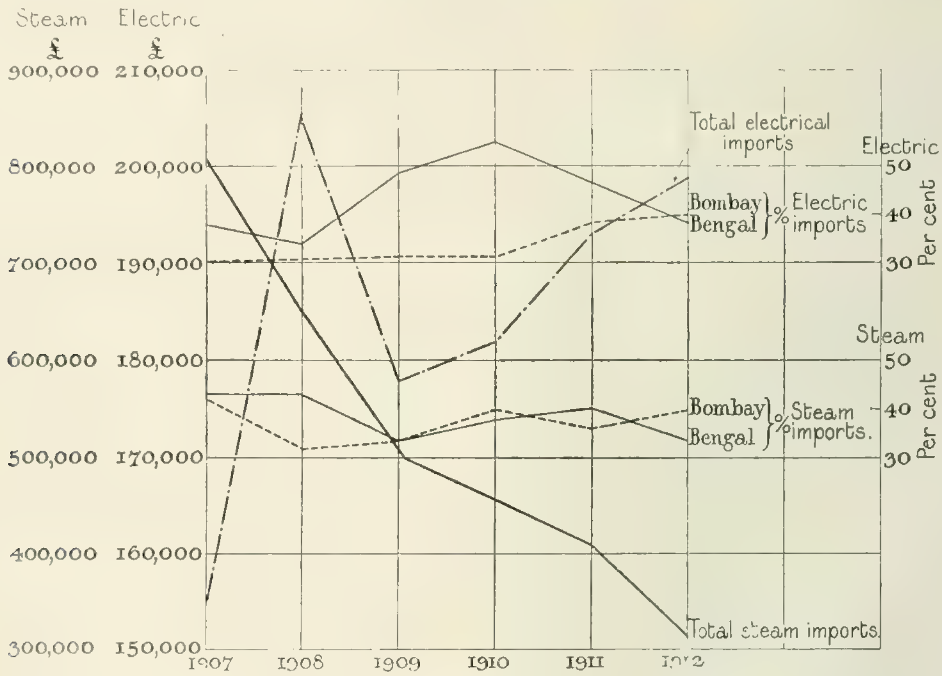


Fig. 1.—Relative Increase of Electric Imports and Decrease of Steam Imports, 1907–1912.

for a fair percentage of the Indian electrical trade they must be prepared to send out to the country their very best power men and not merely one commercial engineer. They must further be prepared to establish themselves on their own account in at least the two largest industrial centres of India, and be prepared to undertake the electrification of mills and factories from A to Z and not against c.i.f. or f.o.b. prices. This method would ensure the confidence of mill-owners and their engineers, and such British firms as were established in India in this way would be able in a very short time to build up a lucrative business.

The pioneering work may now be regarded as having been accomplished—in the majority of cases at the expense, it must be admitted, of the purchasers—and the field therefore for electrical power for industrial purposes in India to-day is one which if handled to advantage by engineers of experience should yield a handsome return Germany has supplied no less than 32,000 kw., the United States 17,000 kw., Switzerland 10,000 kw., and England only 7,500 kw. of the electrical generating plant. In the author's opinion this is due chiefly to the greater standardization covering a large range of voltages, in many cases from 220 to 6,000 volts, which allows foreign manufacturers many opportunities of putting forward standard plant where British manufacturers are obliged to quote higher prices to cover special construction; and in addition the time required for delivery of the plant in the case of the British firms will in the majority of cases be considerably in excess of that of the Continental firms. It must also be borne in mind that Continental makers are fully alive to the conditions under which electrical plant has to work in India, and have spent both time and money in experiments before deciding on the standardization of plant intended for export to a tropical country. Except in some isolated cases, however, the same cannot be said of the

[illegible] [illegible]

TABLE 4.

Public Electric Supply Conditions in India.

[illegible]

TABLE 5.

Meteorological Observations taken in Bengal, 19[illegible]

Name of Reading	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Barometer (corrected)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Dry Bulb Thermometer Fahr.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Wet Bulb Thermometer Fahr.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Humidity per cent	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Rainfall inches	Nil	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Nil
Temperature of River Water Fahr.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

[illegible] market.

CLIMATIC CONDITIONS

[illegible] humidity reaches a figure of 95 per cent with a tempe- [illegible]

[illegible]

[illegible] electricity for power purposes is available at c[illegible]

was preferable to interpose transforming plant, reducing the pressure to 500 volts for the supply to the motors. A large percentage of "burn-outs" on low-pressure motors (220–500 volts) has been directly traceable to the humidity, and it was thought by a number of engineers that the installation of high-pressure motors would be coupled with the risk of a still greater number of breakdowns due to this cause. It seems, however, to the author that the insulation on the average low-tension motor to prevent internal short-circuiting between successive turns due to the difference of potential between them is insufficient to prevent the percolation of moisture from an external source, whereas the insulation necessary on 6,000-volt mains to prevent internal short-circuiting due to the potential difference between successive layers is more than sufficient to prevent the percolation of moisture from an outside source. The author has in many cases supervised the installation of motors to run at 6,000 volts, and with one exception excellent results have been obtained.

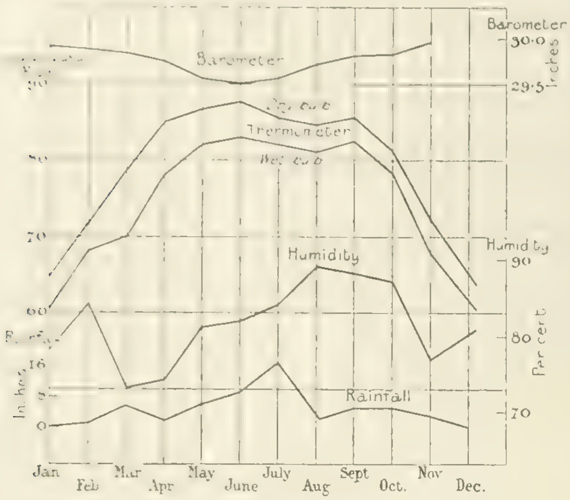


FIG. 2.—Meteorological Observations, Bengal, 1912.

Lack of Home Capital for Electrical Enterprises.

Another factor which has hampered the development of electricity for industrial purposes in India during recent years has been the lack of English capital for projected industrial enterprises for utilizing either water power or coal near the pit's mouth for the generation of electric power for transmission at a cheap rate for mill and factory use.

In the collieries of Bengal, which raise no less than 12,000,000 tons per annum (see Fig. 3), a sound practical scheme was projected a few years ago for the centralization of a power house for supplying electric power to the collieries in general, but owing to the lack of both capital and co-operation between colliery owners the scheme fell through, with the result that there are now scattered over the coal-fields a number of small electric power houses working with both unfavourable power and diversity factors, so that the economy it was hoped to achieve by the use of electric power has to a great extent not been realized. The coal consumption at the collieries (Fig. 3) indicates that at least 85,000 b.h.p. is awaiting electrification.

Another favourable project which fell through owing to lack of capital was the Mourbhunj water-power scheme, which contemplates harnessing the water power available at Mourbhunj for providing a cheap source of electric supply to the mills and factories in and about Calcutta. Taking into consideration the fact that the 85 mills at work in the vicinity of Calcutta utilize altogether approximately 100,000 i.h.p., the success of this scheme would have been assured, as it is quite possible that had capital been forthcoming substantial guarantees would have been obtained from the mills and factories for the supply of current to

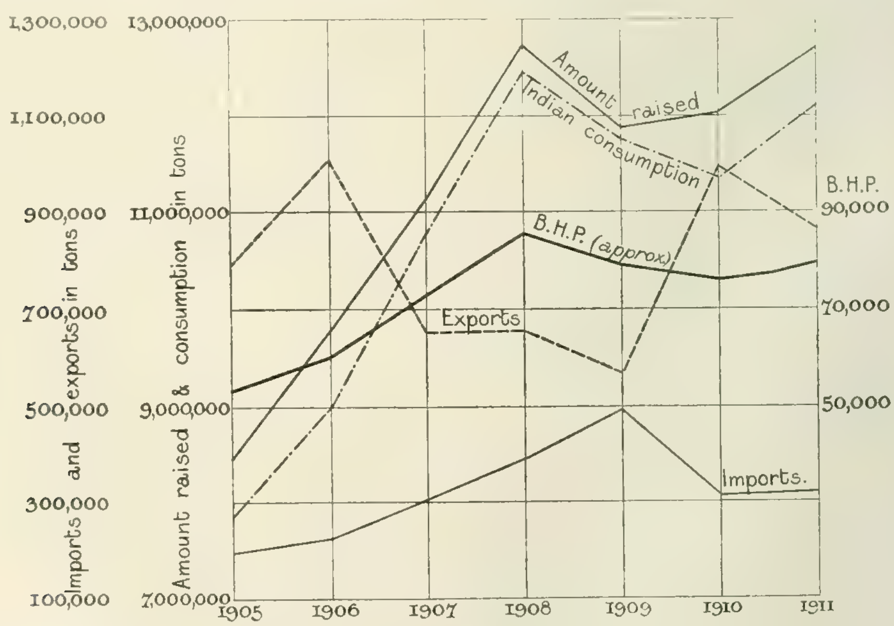


FIG. 3.—The Coal Industry in India.

[illegible]

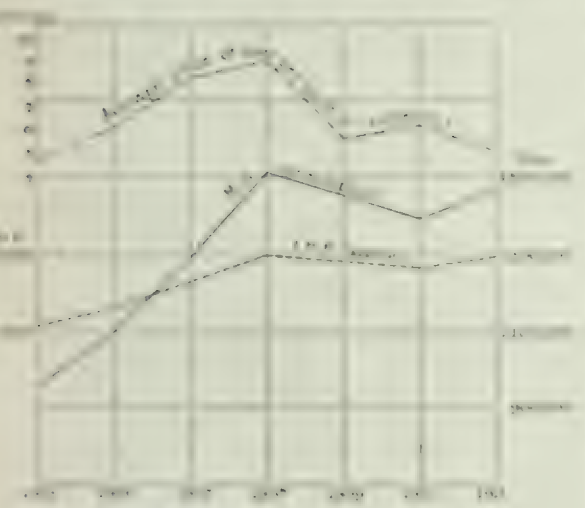


Fig. 4.—[illegible] Mills and [illegible]

[illegible] against the use of electric power for industrial purposes, and although to-day this feeling has to a great extent been overcome, it is still a matter of considerable difficulty to convince owners and others that, apart from the saving in capital outlay and running expenses, inherent advantages appertain to the electrical drive which are not possible of achievement with steam.

In textile mills the steady and uniform speed results without doubt in a better quality texture, and the output over the same running hours is materially increased to an extent depending upon the careful lay-out of the machinery, but unfortunately in very few cases, if any, are manufacturers prepared to guarantee these results. Although they are convinced in their own mind that such is the case it is rarely that one is able to induce manufacturers to [illegible]

[illegible]

[illegible] wise, viewed from the manufacturers point of view, of taking a supply of electrical energy from a public company in preference to generating current on the premises. On this point a great deal of controversy has lately taken place, and as a matter of fact this point is being keenly [illegible] at the present moment in one of the largest [illegible] of India, so that the views of engineers in charge of English supply companies would be of interest.

On the one hand there is the mill-owner wishing for a supply of current at an abnormally cheap rate, and on the other hand there is the executive of the public supply company called upon by the shareholders to pay a handsome dividend on the capital of the company. There is, however, little doubt that for small concerns [illegible] it is far more economical for consumers to take a supply from a local company; but in the case of [illegible] a 10 to 12 hour daily load throughout the year, manufacturers realise that with equal facilities for an adequate supply of water for condensing purposes and equal rates for coal

they are in a position to generate electric power as cheaply as a public supply company. The latter, however, are obliged to add to their generating costs a proportionate charge on the capital sunk in their whole undertaking and a similar charge to cover executive costs, as well as a reasonable percentage of profit. Whereas the manufacturer has only to add to his generating costs the standing charges on the capital outlay necessitated by his plant alone. It must be borne in mind that the keen competition in India to-day in the jute, cotton, flour, and coal industries, increases the importance of a thorough grasp both by the manufacturer and the station engineer of all factors, both commercial and otherwise, which may reduce the mill or factory cost of the finished product to a minimum. Although the mill-owner's responsibility will be lessened by taking power from a public company, he cannot afford to do so until it is conclusively proved, apart from other advantages, that it will be more economical than generating power on the premises. It is true that other factors such as the saving in superficial area—which is an important item in the two largest industrial centres in India—economical expansion, reliability, and the extent to which an interruption of any one section of the mill or factory may affect the returns and cheque-book, ventilation, cleanliness, and the safety of operators, are all dependent to a greater or less extent on the nature of the power delivered to the productive machinery, and are essentially factors controlled by the characteristics of the drive installed. Unfortunately, however, these are factors to which the average manufacturer will give but scanty consideration compared with the importance attached to the figure at which it is possible to generate electric power on the premises compared with the price demanded for similar power from a public supply company.

It appears a matter of difficulty to convince manufacturers of the fact that the current supplied by the company represents effective power, whereas in generating power on the premises the difference of cost between indicated and actual horse-power—in which must be included such losses as may be occasioned in the boiler and engine house as well as in the main transmission drives—has to be borne by the mill-owner.

Another point often lost sight of by the mill-owner is the fact that in the event of the power supply being taken from a company he is in a position to concentrate his efforts and to devote his entire attention to perfecting the conditions under which he is manufacturing, whereas by generating current on the premises he assumes responsibility for plant with which he has probably had little or no experience.

Desirability or Otherwise of a Heavy Power Load for Supply Companies in India.

The conditions under which the electric supply companies operate in India do not form a true analogy with stations at home, in so far as in India during nine months of the year a steady power load due to fans is maintained throughout the 24 hours. It is true that the peak lighting-load is superposed on the fan load, but the resultant station load-factor (defined as the ratio between the mean and the maximum load) may average as high as 65 per cent. It therefore becomes a matter of very serious consideration as to whether a very material advantage is to be gained by an Indian public-supply company catering for heavy mill loads which will again be superposed on the fan and lighting peak-loads.

It must be remembered that the revenue per unit obtained from the two latter loads is far in excess of the price which it is possible to charge the mills and factories for a supply in bulk. Is it therefore worth while to put down additional plant for supplying current to mills and factories for which a comparatively small return can be asked when such a plant cannot be utilized for earning a bigger return per unit by supplying energy for lighting and fans? It is true that the standing charges, as well as to a limited extent the running charges, per unit generated are essentially inversely proportional to the size of the plant installed in the power house and to the ratio between the maximum and average load on the station. The nearer this ratio approaches unity the greater is the earning capacity of each killowatt of plant installed in the station, or, inversely, the cost of power for a given profit decreases with the increase of this ratio.

Apart from these factors, however, the question of distance becomes vital in the case of transmission of power in bulk in a densely populated district from a station having a load factor of about 65 per cent for the supply of current to small consumers for fans and lights.

Take, for instance, a concrete case where an application was received for the supply of electric power in bulk averaging 15,000 b.h.p. to a mill, equally well placed as regards the supply of water and coal, working 11 hours a day and situated approximately 10 miles distant from a power house generating current at 6,000 volts 3-phase 50 cycles. Is it going to pay the power company to cater for such a load? In the first place the expenditure under the heading of cable alone would amount to approximately £30,000, as the district is too thickly populated to allow of overhead mains, and if the supply company deemed it necessary to lay down a duplicate cable to ensure reliability and immunity against breakdown this figure would be at once doubled. In addition, the power load will be superposed on the fan and lighting load, and with a station having a load factor of 60 to 65 per cent additional plant would therefore be required. In the event of the mill doubling its plant and requiring twice as much power, additional cable and plant would again be required to be installed.

The earning capacity of such a load, viewed from the station point of view, would be almost a negligible quantity, as the rate obtainable for such power would be limited to an extent depending on the figure for which the mill, situated at an equal advantage with the supply company, could generate its own power. It is true that such a load would tend to decrease the station running charges per unit, but not necessarily the standing charges when so great a capital outlay is entailed in providing for such a load, and if care is not taken to limit the sale of power for such purposes the earning capacity per kilowatt installed in the station may easily be decreased to a greater extent than it is possible to reduce the standing charges per unit generated by the introduction of such loads.

It appears, therefore, to the author that a point is reached when it will not pay a public supply company to take on cheap power loads unless the rate charged for such power includes a proportionate charge on the total

[illegible] may happen that through a shortage of raw materials or [illegible]

It would be of interest to learn how the question of the [illegible] that in the majority of cases it is of little use for the mill-owners to seek advice from the contractor, as he, as a rule, [illegible] motors but the complete primary plant, and therefore, [illegible] capital, the contractor apparently cannot be relied upon to [illegible]

[illegible] Companies in India

The largest of the public-supply companies in India is [illegible] pany, whose power station now under construction at Khopoli, in the Bombay Presidency, will when completed be in a position to supply 30,000 h.p. to the Bombay cotton mills, and at a later date 60,000 h.p. The water power for this scheme is obtained from the Bhor mountains, on the summit of which, at a height of approximately 1,800 ft., large reservoirs are in course of construction. The lakes are formed by constructing masonry dams across two valleys, Lonavala valley and Walwhan valley, whilst the third, known as the Shiratway valley, will form a reserve for future extensions. The area of the Lonavala lake is approximately 1,000 acres, and is formed by a low dam 3,800 ft. in length with a water depth of 26 ft.; the capacity is approximately [illegible] cub. ft.

[illegible] Walwhan lake is formed between two spurs of hills by a dam 4,500 ft. in length; the area is approximately 1,540 acres, and its capacity 2,800,000 cub. ft. The dam is of solid masonry fitted with sluices to control the water to the duct leading to the forebay.

[illegible] beyond the Walwhan lake, with which it will be con- [illegible] through the dividing ridges and steep hills, and it will [illegible] long, and will be operated at a pressure [illegible]

[illegible] the generator pressure 2,170 volts 3-phase 25 cycles. The bulk of the power is used on the Kolar Gold-fields, some 92 miles distant from the falls. The transmission [illegible] circuits 2,080 volts. Street [illegible] ment, and will be installed immediately. In this case also the station and transmission plant has been purchased from the Continent and America.

The Calcutta Electric Supply Corporation is next from the point of view of size, viz. 15,000 h.p., used almost [illegible] private lighting and fans. The generating pressure is [illegible] sub-stations is carried out at this pressure, interconnected motor converters being used to transform to continu- [illegible] purposes as against the supply, at very much more remunerative rates, for lighting and fans.

The Bombay Tramways and Electric Supply Company have a station of 12,000 h.p. capacity supplying power to [illegible] large consumers and the outlying districts.

[illegible] installed by the Government of Kashmir, where a station [illegible]

any details in connection with this station as at the moment the whole system is being reconstructed with a view to its being in a position to meet the demands of the Presidency, which demand, however, for some time to come is only likely to consist of a lighting and fan load.

Detailed data concerning the principal power supply companies in India has been tabulated in Table 1.

Private Electrical Installations in India.

The largest of the private generating stations in India is perhaps the power house of the Tata Iron and Steel Works at Sakchi, Bengal, where three steam turbo-generators each of 1,250-k.v.a. capacity have been installed for the supply of energy for general power purposes, with the exception of rolling. In this case also the electric plant was obtained chiefly from the Continent.

A number of railway workshops and mills have installed minor installations, which, however, call for no special mention. For the information of electrical manufacturers a list is given in Table 3.

Electric Traction.

There are a number of electric tramways at work in India on the ordinary 500-volt continuous-current system, but up to the present no railway has adopted electric traction. A number of the Indian State-owned railways, however, have now under consideration important projects for the electrification of inter-urban and main lines, and it is quite likely that many such schemes will mature in the near future.

The Indian Electricity Act, 1912.

The first Electricity Act passed by the Indian Government came into force in 1903, but it was soon apparent that the Act was defective in many of its measures, and in 1910 a new Bill was drawn up by the Government of India with the assistance of eminent authorities. This Act became operative in January 1911.

It is not proposed to deal at any length here with the Act, but it may be mentioned that few, if any, irksome restrictions have been imposed on the general use of electrical power for factory, mill, or colliery work. The interests of consumers taking a public supply have been well looked after, and the stipulations controlling the installation of high-tension plant are such that it is quite possible for British manufacturers to comply with the same without materially altering their standard plant designed for the home market.

Conclusions.

In conclusion it may be said that the more important manufacturing centres of India to-day are fully alive to the advantages appertaining to the installation of electric plant, but if British manufacturers are desirous of obtaining a fair percentage of this trade it is essential that they should send out to the country their best men and should endeavour to standardize a special line of machinery suitable for the unfavourable climatic conditions and unskilled treatment to which the machinery is subjected.

Mill-owners, agents, and laymen in general must on their part be prepared to lay aside pre-concerted ideas on the electric drive and endeavour to grasp simple technical facts, whilst engineers must on the other hand be prepared to broaden their outlook to embrace not only technical points but elementary commercial factors. In this way the electrical industry in India will prosper to the advantage of both the mill-owner and British electrical manufacturers.

Table 3 has been compiled by Mr. M. C. Rutnagur, Editor of the *Indian Textile Journal*.

Table 3.

Electrical Power Stations and Plants in India (*Working and in course of erection, June* 1913).

Ahmedabad Cotton Mill	Ahmedabad
Akola and Mid. India Gin. Factory	Akola
Anglo-Indian Jute Mill...	Calcutta
Apollo Cotton Mill ...	Bombay
Assam Oil Mill	Assam
Baroda State Plant ...	Baroda
Bengal Iron and Steel Works	Barakur
Bengal Nagpur Railway Works	Calcutta
Bengal and North-West Railway	Lahore
Birkmyre Brothers' Jute Factory	Calcutta
Bikanir City Flour Mill	Bikanir
Bikanir City Oil Mill ...	,,
Bikanir State Plant ...	,,
Bombay Baroda & Cen. India Rly. Works	Bombay
Bombay Cotton Mill ...	,,
Bombay Electric Tramway & Power Co.	,,
Bombay Flour Mill ...	,,
Bombay Municipal Sewage Works	,,
Bombay United Mills ...	,,
Buckingham Mills ..	Madras
Budge Budge Mills ...	Calcutta
Burma Railway	Rangoon
Burma Oil Co.'s Depôt...	Calcutta
Bombay Telephone Co.	Bombay
Calcutta Electric Supply Co.	Cossipore
Calcutta Ordnance Dept.	,,
Calcutta Real Property Co.	Calcutta
Calcutta Telegraph Dept.	,,
Calcutta Electric Supply Corporation	,,
Cauvery Falls Works ...	Mysore
Cawnpore Harness Factory	Cawnpore
Caxton Printing Works	Bombay
Central Jute Press ...	Calcutta
Civil Engineering College	Sibpur
Colaba Land Cotton Mill	Bombay
Colombo Tramway Co....	Ceylon
Cossipore Gun and Shell Factory	Cossipore
Crescent Cotton Mill ...	Bombay
Crown Cotton Mill ...	,,
Currimbhoy Cotton Mill	,,
Cordite Water Power Station	Nilghiris
David Cotton Mill ...	Bombay
Dawn Cotton Mill ...	,,
Delhi Tramway Co. ...	Delhi
Dum Dum Ammunition Factory	Dum Dum
East India Coal Co. ...	Calcutta
East Indian Rly. Works	,,
E. Pabaney Cotton Mill	Bombay
E. D. Sassoon Cotton Mill	,,
Elphinstone Cotton Mill	,,
Empress Cotton Mill ...	Nagpur
Fazalbhoy Cotton Mill...	Bombay
Finlay Cotton Mill ...	,,
Fort William Flour Mill	Calcutta
Great Indian Peninsular Railway Works	Bombay
Godak Water Falls ...	Belgaum
Gold Mohur Cotton Mills	Bombay
Government Pub. Works Department	Ootacamund
Government Press ...	Madras
Government Printing Press	Yeravda
Government Secretariat	Calcutta
Gwalior State Plant ...	Gwalior
Gwalior State Railway...	Gwalior
H.M. Mint	Calcutta
Hindoosthan Cotton Mill	,,
India Jute Mill	,,
Indian Bleaching and Print Works	Bombay
Indore State Installation	Indore
Industrial School ...	Lucknow
Jacob Sassoon Cotton Mill	Bombay
Jamadaba Colliery ...	Jamadaba
Jamshed Cotton Mill ...	Bombay
Jubilee Cotton Mill ...	,,
Kolar Gold-fields Plant	Mysore
Madhawji Dharamsey Cotton Mill	Bombay
Madras Electric Supply Corporation	Madras
Madras Portland Cement Works	,,
Madras Telegraph Dept.	,,
Madras Corpn. Plant ...	,,
Mahmedbhoy Cotton Mill	Bombay
Mathematical Institution	Calcutta
Monarch Flour Mill ...	,,
Madras Electric Tramways, Ltd.	Madras
Munnar Hydro-electric Works	South India
Mussorie Hydro-electric Plant	Mussorie
Nepal State Hydro-electric Works	Nepal
New City Flour Mill ...	Calcutta
New City of Bombay Cotton Mill	Bombay
New Kaleewarar Cotton Mill	Coimbatore
North-Western Railway Works	Lahore
Noondydroog Mines ...	Mysore
Ocean Jute Press ...	Calcutta
Oudh and Rohilkhand Railway	Oudh
Patiala State Plant ...	Patiala
Phœnix Cotton Mill ...	Bombay
Pondicherry Electric Inst.	Pondicherry
Quetta Residency Station	Quetta
Quetta Staff College ...	,,
Rangoon Electric Tramway	Rangoon
Ranigunj Colliery ...	Ranigunj
Ripon Cotton Mill ...	Bombay
Sarah Bridge Plant ...	Sarah
Sun Jute Press	Calcutta
Swan Cotton Mill ...	Bombay
Suraj Jute Press ...	Calcutta
Sorab Cotton Mill ...	Bombay
Srinagar Hydro-electric Works	Kashmir
Shri Buldeo Cotton Mills	Hathras
Simla Hydro-electric Works	Simla
Sun Cotton Mill	Bombay
South Indian Railway ...	Nagapatam
Taj Mahal Hotel ...	Bombay
Tata Swadeshi Mill ...	,,
Tata Hydro-electric Works	Lonavla
Tata Iron and Steel Works	Kalimati
Thomason Engineering College	Roorkee
Tibutil Gold Mines ...	Anantpur
The Times Press	Bombay
Upper Swat Canal ...	Malakand
Victoria Jute Press ...	Calcutta
Western India Cotton Mill	Bombay

DISCUSSION ON "AUTOMATIC PROTECTIVE SWITCHGEAR FOR ALTERNATING-CURRENT SYSTEMS."*

SCOTTISH LOCAL SECTION, [illegible] MARCH, [illegible].

[illegible] to maintain the supply with faults on isolated feeders until [illegible] earth the neutral. We recently had an experience which is perhaps worth putting on record. A fault developed on a transformer about four miles from the power station and was proved to have started as an earth. It produced [illegible] apart from the original place where the trouble occurred. It caused such a shock to the system that all the synchronous plant in the stations got out of step. I need not describe what followed, as it is obvious. In order to avoid that sort of thing we hope that by using to a considerable extent core-balance protection we shall be able to get rid of what are really minor faults to earth without affecting the rest of the supply. We are fortunately in [illegible] transformers, which are at present supplying the instru- [illegible] transformers. We have made laboratory tests which have [illegible] relays—two poles for overload protection and the third to take care of faults to earth. The change will thus be [illegible] the classification of protective devices, the aut[illegible] to have included the first and second items in the third; [illegible] the whole field. The author says on page 159 that "such [illegible] few amperes." That may be so, but the problem with [illegible] If that [illegible] of the [illegible] previously referred to are not of [illegible] connection with the Glasgow prol[illegible] means the last word. Where a supply is given to sub- [illegible] to "selective action with leakage protective a[illegible] relays." It is unlikely that an engineer in [illegible] protection problem would select either of [illegible] power station the prot[illegible] fault until something like three seconds have elapsed, and probably by that time the generating plant would have [illegible] he states that to keep down static disturbance[illegible] the system. What [illegible] current of the system, but I should li[illegible] the further statement that "there are [illegible] metallic arcs in air and oil for us to lay dow[illegible] point." I should like also to have the author's views as to how long the neutral resistance ought to carry its normal [illegible] that the adoption of the system rather en[illegible]

* [illegible]

Mr. Page

feeder, while in feeders BB the currents are stated as 25 and 75 amperes. Are we to assume that power is taken off at the first sub-station busbars? Should not these figures be 50 and 150? With the biased protective relay is there no trouble when the first or faulty feeder has been cut off, in that the restraining coil energized by that feeder is then not operative and consequently the coil which has been restrained previously by the restraining coil will now open the circuit-breaker on the sound feeder? In this connection reference is made to the use of auxiliary switches on the circuit-breakers. I do not quite see what these auxiliary switches are going to do. When a circuit-breaker comes out it can be made to open an auxiliary switch, but the opening of that switch is still going to leave the sound feeder unprotected in case a fault should develop on it whilst the faulty one is being repaired. What I have just said has also a bearing on Fig. 21. The sub-station end will be cleared first, but if the relay settings are not kept very high the biased relay will trip not only the faulty feeder but also the sound one at the power station. We have a good proportion of Merz-Price protective gear in the West of Scotland and it is satisfactory provided its limitations are thoroughly understood. The split-conductor system, while we have not had any experience of it, promises to prove very satisfactory and we are adopting it on all new work. I agree that it is best to split the conductor at the switch. We have heard a good deal recently of the system involving a copper sheath to the cables, the relays being connected between the sheath and the lead. If the author has had any experience with this system it would be interesting to have his views. Under the heading "The Ideal Combination of Apparatus" on page 168 the core-balance system is recommended by the author for the protection of all open-ended feeder circuits. The only thing the core-balanced system can do is to clear the faults which are initially faults to earth, but all faults are not faults to earth. It seems to me that the author should have included something else to take care of short-circuits between phases. The other advantages of the combination which have been suggested are so obvious that it makes one wish that we could start all over again.

Mr. Macleod.

Mr. D. M. Macleod: In 1904, Messrs. Merz and McLellan read a paper before the Institution* and they made a remark that in their opinion protective devices required more attention than any other part of an electrical system in order to secure greater immunity from failure; I think that that remark may be repeated with truth to-day. When I read the present paper I could not but recall a demonstration which I witnessed in London in 1904 by Mr. Leonard Andrews, who gave some very interesting experiments regarding balanced selective protective apparatus. In fact Mr. Andrews' remarks on that occasion were strictly relevant to this paper and I think he must be regarded as one of the early pioneers in connection with selective devices. I think that as a general rule the number of faults caused by protective devices exceeds the total of those arising from all other causes. That statement of course has to be qualified by the fact that there appears to be a limit to the pressure—the limit might be put at 5,000 or 6,000 volts—at which one might expect satisfactory working. Above that pressure, however, there seems to be a distinct effect upon the protective transformer windings, with the result that, in the course of time, instead of preventing trouble these transformers really cause trouble. So much is that the case, that if one were to take into account the failures of supply arising from series transformers, one could prepare a formidable indictment against protective devices and make out a good case for their elimination. Of course one's instinct teaches one that that would be a false step to take. The proper course would seem to be to concentrate designers' attention on the improvement of these protective devices, and I have no doubt that in the course of time we shall reach a point when consulting engineers will not only insist upon their cables being tested to double the working pressure after 24 hours' immersion in water, but will also apply the same test conditions to series transformers and other protective devices. There are one or two other points in the paper to which I should like to call attention. With regard to the use of core-balance devices, it seems to me that these devices would remain inoperative in the event of a fault developing upon a sub-station busbar, or upon any apparatus directly connected with the busbars. I mean by that any apparatus installed between the oil circuit-breaker and the busbar proper, because obviously a fault developing there would still remain upon the system whether the oil circuit-breaker operated or not. This is one of the limitations not only of the core-balance system but also of all protective systems using this principle. One must depend upon overload relays at the generating station to clear all such faults. There is a point I wish to refer to in connection with current transformers. Take, for instance, the series transformers for an 11,000 volt 3-phase transformer unit having a ratio of 8 to 5. The primary windings would be of comparatively small gauge. One very great danger in using such small transformers is that in the event of any serious fault developing upon the oil switch or in the main transformers these windings are apt to burn out and put a busbar fault upon the system, with very disastrous results. In some cases I have used in conjunction with these small transformers oil fuses and these have given very good results indeed. The only advantage of the split-conductor system is, in my opinion, the absence of the series transformers, which is a clear gain, but against that one has to put the added complications to the switchgear. For example, in a 3-phase oil switch one must provide a switch with nine porcelains and nine contacts instead of five as would be the case for 3-core cables. In addition to that there is the trouble of joining these cables.

Mr. Stevenson.

Mr. A. F. Stevenson: I should like to ask the author to tell us what was the constructional defect on the line which caused the one failure mentioned in his reply to the discussion at one of the other Local Sections. We thought that this apparatus was to deal with defects on the lines. A cable fault occurred on the low-tension side in a colliery supplied by the Durham Power Company's system, resulting in extensive damage to the e.h.t. line and to the plant in the sub-station some miles away. As this is a recent installation I presume that the "split-conductor" protection was in use, and it would be interesting to hear the reason for its failure to save the plant. The fault was due to the laying of bitumen cables over buried steam pipes.

Mr. Newington.

Mr. F. A. Newington: I do not propose to discuss the paper, but there is one point which neither the author

* *Journal I.E.E.*, vol. 33, p. 696, 1904.

[illegible]

[illegible] action over older methods, it does not isolate the generator in case of failure of excitation as does the reverse-current [illegible] exciter could be used to hold in one of the current-trans- [illegible] that the remaining feeder would be cut out automatically [illegible] With regard to Fig. 20, would it not be better to put the [illegible] With regard to the split-conductor cable, I suppose the light insulation between the concentric conductors of each phase will have to be good enough to withstand the full star voltage, otherwise there is a chance of this insulation breaking down when a fault comes on. In the concluding remarks under B, namely, for the protection of all open- [illegible] that it would seem better to provide for these conditions in the first expense.

[illegible] my classification of protective devices is in effect a [illegible]nation of overload and reverse-current relays in [illegible] are defective unless they are so [illegible] class 3. Overload and reverse-current relays as generally employed do not operate "only [illegible] channels," but they can be made to do so by the means I have [illegible]

[illegible] from 10,000 to 3,000 volts de[illegible] on the 3,000-volt side will appear on the e.h.t. side as an [illegible] any leakage apparatus on that side.

Mr. Duddell has made us familiar with the conditions [illegible] an insulated system where we have [illegible] arc is snapped out very suddenly and periodically with a high frequency. This sets up surges with a steep wave front, and such surges seek out the weak spots in the system. The energy liberated is usually small and results in a perpetual bombardment of insulating material, which sooner or later breaks down. [illegible] ance. This phenomenon is prevented if the capacity of [illegible] stitutes an effective shunt. Clearly an earth connection passing 1 ampere where the capacity current is 50 amperes would have no appreciable effect, but I believe the figures [illegible] resistances used to be rated to carry their maximum current continuously for 15 seconds. This, however, has proved insufficient and we now employ a 2-minute rating, the resistance being designed to carry the maximum current for two minutes without destruction. In practice this rating gives ample time to enable the attendants to take control in case apparatus fails, because in much less than two minutes the energy liberated at the fault will cause a reduction of the current by the destruction of material.

[illegible] referred to them as connected by independent feeders. Mr. Page objects to this expression, but I have previously defined the sense in which the expression is to be interpreted, and my definition covers machine cables. I quite agree that there is not much opening for core-balance [illegible]

Mr. Wedmore

there should be 50 amperes in each feeder on the left-hand side of the diagram.

When using such devices as balanced relays on pairs of feeders, it is necessary to protect the sound feeder in a pair from disconnection when the faulty feeder is cut out. I have referred to the use of auxiliary switches for this purpose. These are operated by the oil-switch mechanism and may be used to cut the relays out of circuit, or to cut in a fuse in shunt to the operating coil, thus converting the relay on the sound feeder into an inverse time-limit relay. This has been done successfully. The auxiliary switch has to operate whilst the oil-switch contacts are separating. When the feeder is put back into service after the fault has been repaired, the order of action is reversed, and on closing the oil switch the relay is restored to service, just after contact is made. The auxiliary switches introduce a certain amount of complication in the wiring and are not generally situated conveniently close to the relays. The time-limit fuse also is not very satisfactory for this service, as it gives no delaying action on a severe fault. An alternative arrangement is now being used which is advantageous. On one relay operating, it is arranged to cut the connection of the tripping circuit of the relays controlling the other feeder, thus putting them instantly out of action. The necessary connections are self-contained on the relays and no current is broken on the relay contacts. The relay is reset by hand just before the faulty feeder is to be restored to service. The relay settings are put a little above normal load so as to admit of this. Where the whole protection is obtained by the use of balanced overload relays such a setting is necessary in any case, as during the development of a fault it will be found that, at the end remote from the source of supply, the current in the faulty feeder reverses, and whilst doing so, for a moment, it carries less current than the sound feeder.

On a large system this is undoubtedly the best method of disposing of the difficulties referred to. On such a system further protection is required in order to guard against the possibility of a busbar fault. This may be done by the employment of overload relays with a small fixed time-limit inserted in feeders at the source of supply. These will not have time to operate so long as the proper protective apparatus removes the faults and so long as there is no failure on the busbar side of the apparatus. If, however, there is an oil switch or busbar failure or a failure of protective apparatus, these relays take care of the emergency. This protection is sufficient to take care of the emergency condition which arises when a faulty feeder is cut out in the manner described, leaving one sound feeder temporarily connected to the system without other protection. On existing installations, time-limit relays with a fixed time characteristic, or a fixed minimum time characteristic, are, as a rule, already in existence and should be retained, when balanced overload relays are added to improve the conditions.

Mr. Wedmore

I have heard of no experience with the proposed protective system referred to by Mr. Page in which the cables are built with special copper sheaths. It is obvious that the device provides no protection against faults between phases, and it is not yet clear how faults in the end bells are to be taken care of. I anticipate that interlocked relays suitably arranged will give better protection at a small fraction of the cost. Core balancing is available for taking care of faults to earth, but it is of course necessary to furnish means for protection against faults between phases.

Mr. Macleod has evidently had very unfortunate experience with current transformers, but I cannot agree that on systems operating above 6,000 volts one must expect trouble with current transformers. One can obtain current transformers for such service in which the insulation is in the form of a solid porcelain tube, and is as good as that which is used in the oil switches and connections generally. For high voltages it is quite practicable to furnish Merz-Price, split-conductor, and core-balancing apparatus with transformers having bar primary windings, and which can be insulated with solid tubes of insulating material. This apparatus would withstand the test conditions which Mr. Macleod suggests. There is a great danger in the employment of current transformers with multiple-turn primaries of small cross-section on large systems. As a general rule it will be found that the smallest transformer near the main busbar should have a normal current capacity not less than 1/20th of the total output of the plant. It is not clear to me, however, why a failure of such a transformer should produce a busbar fault. The transformers should be on the safe side of the oil switches.

In reply to Mr. Stevenson, who refers to the case in which a split-conductor line was disconnected due to a fault in the construction, I would say that the apparatus operated quite correctly to cut out the faulty line but the line need not have been cut out. I have no access to the records of the troubles which Mr. Stevenson refers to as having been met with on the Durham Power Company's system, and there is no evidence as to what the system of protection was, or as to the circumstances of the failure. Protective apparatus is not a panacea for all the troubles to which electrical apparatus is subject.

Mr. Seddon criticizes the arrangement shown in Fig. 20. One of the objects of this arrangement is to avoid the necessity for opening out the neutral ends of the machine windings for the insertion of protective transformers. Machines of the class referred to are so built that it is practicably impossible that an earth fault should develop simultaneously on both windings.

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THE POWER SUPPLY OF THE CENTRAL MINING-RAND MINES GROUP.

By J. H. Rider, Member.

[illegible]

Introductory.

[illegible] tracted with the power company for the whole of their [illegible] way with the one entitled "Power Supply on the Rand,"* read by Mr. Hadley before the Institution on the 13th March, 1913. Mr. Hadley's paper dealt with the general power supply given on the Rand by the Victoria Falls and Transvaal Power Company, Ltd., and its associated company the [illegible]

[illegible]

- Modderfontein "B" Gold Mines, Ltd.
- New Modderfontein Gold Mining Company, Ltd.
- [illegible]
- Geldenhuis Deep, Ltd.
- Nourse Mines, Ltd.
- City Deep, Ltd.
- The Village Main Reef Gold Mining Company, Ltd.
- Village Deep, Ltd.
- [illegible] Ltd.
- [illegible] Gold Mining Company, Ltd.
- [illegible]
- [illegible]ated Mines, Ltd.
- Durban Roodepoort Deep, Ltd.

and they will be referred to in this paper as the Central [illegible]

These companies are under the financial and engineering [illegible] Ltd. (formerly H. Eckstein & Co.), and Rand Mines, Ltd [illegible] annum and produce about 36 per cent of the [illegible] output of the Transvaal, or about 14·5 per cent of the total gold output of the world.

[illegible] power requirements of the above mines should be taken from an outside source, it was stipulated that a separate [illegible] Supply Company, Ltd., should be formed [illegible]

[illegible] iging power stations, and the air-compressing station at Robinson Central Deep (a section of Crown Mines, Ltd.). Its overhead and underground transmission and distribu- [illegible] Company, but have been and are at present (1914) interconnected. Under normal working conditions, however, when both power companies [illegible] the two systems will be kept [illegible]

The entire working and operation of the system of the Rand Mines Power Company are under the technical control of the Victoria Falls Company.

Each of the mining companies in the Central Mining- [illegible] Rand Mines Power [illegible]

[illegible]

* [illegible]

from 23 miles east to 12 miles west of Johannesburg, should be supplied with energy entirely from the system of the Rand Mines Power Company, but, in order to lessen the capital expenditure of the two power companies, it was afterwards agreed that certain of the mines, lying at the extreme east and west, should be supplied from the electrical system of the Victoria Falls Company, on behalf of the Rand Mines Power Company. Certain other mining companies, customers of the Victoria Falls Company, are similarly supplied from the electrical system of the Rand Mines Power Company. The obligations of the respective power companies and the privileges of their consumers under their contracts are, however, unaltered.

The whole of the compressed-air supply (with the exceptions noted later) is given from the air mains of the Rand Mines Power Company, and only to the mines in the Central Mining-Rand Mines group. The Victoria Falls Company has, so far, no air-compressing system.

An interim electrical supply, without any liability for damages for stoppages, etc., had been given to certain mines, up to about 8,000 k.v.a., from the stations of the Victoria Falls Company. The permanent supply under the terms of the contract began on the 1st March, 1911.

The history of the first three years of the supply under the contract teaches one outstanding lesson, namely, that it is only courting failure to attempt to give a permanent and reliable supply without a proper reserve of generating and transforming plant. During 1911 and 1912, interruptions were frequent, both in the electrical and air supplies, and, as the fourth generator at Vereeniging was not put to work until October 1913, a considerable amount of load (principally winders) was not changed over to electric drive until then, but was kept working on steam. It was not until August 1914 that the power company was able to supply the whole of the compressed-air load, and up to that date a number of the old steam compressors on the mines were still used.

It is not for the author to explain the reasons for the frequent and sometimes lengthy breakdowns of the generating plant. He has little doubt, however, that some of them were caused by nothing else than continuous overloading, in an attempt to give as large a supply as possible from the existing plant, before the spare plant was ready. A reserve of 25 per cent is not by any means too much, particularly with such large generating units as are used in the power company's stations, considering that the necessary periodical overhauls must put a certain amount out of action almost all the time. Since the full amount (25 per cent) of reserve plant has been available the supplies have been quite reliable, and any troubles have been generally local and of no long duration.

At the end of March 1911 the power company was notified by Rand Mines, Ltd., that its companies would require a total of 70,000 k.v.a. of electricity supply, and 21,000 lb. per minute of compressed-air supply at a gauge pressure of 100 lb., these demands being the aggregate of the demands of the individual mines as measured at the points of delivery.

Experience has shown that the maximum individual demands of the mines for electricity supply have a diversity factor of about 1·14, while the power factor averages about 0·77, so that the above aggregate demand represents a maximum demand upon the electrical system of about 47,300 kw. The load factor of the electrical system is about 75 per cent, and the annual consumption at the rate of about 310,000,000 units. The above figures do not include the energy taken to drive the compressing plant at the Robinson Central Deep station, but the air output from this station is included in the figures immediately following.

The demands of the individual mines upon the compressed-air system vary considerably, and depend largely upon the amount of development work (*i.e.* opening of new ground) in progress. Considerable economies have been made in the use of compressed air since 1913, and the maximum aggregate air demands now vary in the neighbourhood of 18,000 lb. per minute. The diversity factor is also very variable but averages about 1·13, so that the maximum demand upon the compressed-air system is about 15,800 lb. per minute, or 37,900 kw. The load factor is about 34 per cent, and, as an air unit represents 27·441 lb. at 100 lb. gauge pressure, the annual consumption is about 103,000,000 air units.

The energy value of the air unit, and the method of its determination were explained in Mr. Hadley's paper. It is entirely a commercial unit, evolved to suit local conditions, and represents 0·641 of the energy in one electrical unit, assuming isothermal conditions of air compression.

A flat price is paid for the electric and air unit, and is subject to special rebates, depending on the working costs of the power company and the cost of railway carriage of coal.

Owing to the great expense which would have been incurred in carrying air mains to the outlying mines, it was agreed that Modderfontein "B" Gold Mines, Ltd., New Modderfontein Gold Mining Company, Ltd., Bantjes Consolidated Mines, Ltd., and Durban Roodepoort Deep, Ltd., should obtain their compressed-air supply from their own electrically-driven compressors erected on the mines. In the case of Durban Roodepoort Deep, Ltd., a reduction of 5 per cent on the price of the electricity is made for all energy used in driving the compressors, but the other three mines mentioned receive their compressed air at the same price as though such air were supplied through the pipe lines of the power company in the ordinary way. For the time being, however, the three mines have furnished the capital for the compressor plant, but the interest and amortization charges and the working expenses are paid by the power company. The latter is not responsible for any failure in the supply of the compressed air through the mine's own compressors, but only for a failure of the electricity supply driving such compressors.

The air units produced by the compressors on the four mines mentioned are not included in the figure of annual consumption given above, but the electrical energy used to operate such compressors is included in the total electrical units there given.

Mr. Hadley says* in his paper that the electricity "supply is furnished to all mining consumers at 2,100 volts and 525 volts." The present author can only express the wish that this statement were borne out in practice, and he will deal with the effects of variations in pressure, etc., at a later stage of this paper. Unfortunately the contract allows a variation of 10 per cent up and down from the mean pressures of 2,100 volts and 525 volts, or a total range of 20 per cent before any damages become due from

* *Journal I.E.E.*, vol. 51, p. 4, 1913.

[illegible]

[illegible] Plant

The whole of the [illegible] and extra-high-tension [illegible] apparatus at each point of supply on the mine properties is provided by the power company. The transformer and switch houses, however, are provided by the consumer. The transformer houses are brick or concrete structures, and, including the switch-house section, cost [illegible] k.v.a. [illegible] transformer.

The normal declared electric pressures at each point of [illegible] are 2,100 volts and 525 volts, and the consumer is [illegible] to receive its supply at these pressures in any proportions which it may require from time to time.

The power company has to keep available, at each point of supply, one spare transformer for each pressure of supply, of such capacity that, in the event of the failure of a transformer at either pressure of supply, the remaining transformers, including the spare transformer, will be [illegible]. A transformer is considered as [illegible] when its temperature at any time exceeds 80° C., and the [illegible] its bulb submerged in the oil near the top of the transformer. So far, no temperatures exceeding 60° C. have been observed on any transformer when working at its full rated output.

There are altogether 23 transformer houses at the various points of supply, and the ratings of the transformers installed (1914) are as follows :—

Mine	No. of Transformer Houses	Transformer Rating in k.v.a.
Modder "B"	1	6,000
New Modder	2	11,000*
[illegible] Deep	2	10,000
[illegible] Deep	2	[illegible]
[illegible]	2	8,[illegible]
[illegible] Deep	2	7,[illegible]
Village Main Reef	1	4,[illegible]
Village Deep	2	10,500
Ferreira Deep, Ltd. ...	1	[illegible]
Robinson	1	[illegible]
Crown	5	[illegible]
[illegible]	1	7,000
Durban Roodepoort Deep...	1	[illegible]
Total	23 houses	125,750 k.v.a.

* [illegible]

[illegible]

[illegible] pressure of supply.

[illegible]

The number of units of electricity [illegible] the readings of the three meters at each pressure of supply, [illegible] of supply, which allowance does not [illegible] 2 per cent of the number of units as [illegible] readings of the meters.

If the reading of each meter is within 3 per cent of the mean of the reading of the three meters, each meter is considered correct for the purposes of the accounts. If, however, the reading of any meter at any time shows a difference from the mean of the readings of the three meters of more than 3 per cent, then the mean of the readings of the three is taken for the time being, but the [illegible] coefficient which shows an error of more than 3 per cent is re-adjusted. The accounts in respect of the period only during which the meters were found to be in error are corrected.

If at any time two meters only be in service [illegible] the third being under test or repair, the mean of [illegible] parties, provided that such mean is within 3 per cent of the readings of both meters. If the mean of the [illegible] not within 3 per cent, the same procedure is adopted with regard to the re-determination of the accuracy coefficients, and the re-adjustment of the meters and the correction of the accounts as set forth above.

The power company's electric meter and the joint electric meter at present installed are both of the A.E.G. make, while the consumer's electric meter is of the General Electric Company's (U.S.A.) make.

The number of units of compressed air supplied to the consumer is ascertained by an air meter or meters of a type to be approved by the consumer, provided by and maintained at the expense of the power company and connected [illegible]

[illegible] of delivery. The consumer's meters are installed on the delivery side of, and closely adjacent to, the power com- [illegible]

The number of units of compressed air paid for by the consumer is the number of units represented by the mean of the readings of the power company's meter and the consumer's meters. If the readings of the consumer's air meters and the power company's air meters are each within 3 per cent of the mean of the readings of all the meters, each meter is considered correct. If, however, the reading of any air meter at any time shows a difference from the mean of the readings of all the meters of more than 3 per cent, such meter is, as soon as possible, tested and re-adjusted.

After any air meter has been re-adjusted and is re-installed at the point of delivery, the remaining meters are re-adjusted so as to conform with the readings of the said meter. The accounts in respect of the period only during which the air meters were found to be in error are corrected.

During the time an air meter is out of commission while being tested or repaired, the other meters remain in service, and the mean of the readings of such remaining meters are accepted by both parties provided that such mean is within 3 per cent of the readings of each remaining meter. If the mean of the readings is not within 3 per cent, the same procedure is adopted with regard to the testing and re-adjusting of the remaining meters and the correction of the accounts as set forth above.

If one air meter only is installed by the power company, its readings are taken as correct, subject to such corrections as may be agreed upon between the parties as the results of tests conducted under the joint supervision of both parties.

If any air meter which is in use, whether the property of the power company or the consumer, be found at any time to be permanently unreliable or of insufficient capacity, it is replaced by and at the expense of the owner by a meter of a type approved by both parties. The consumer has, however, in such circumstances the option of removing its air meter entirely if it so desire.

In addition to the tests referred to above, routine tests on all electric and air meters are made periodically by the technical staffs of both parties acting jointly.

The term "reading of electric and/or air meter" is defined in the contract as meaning the dial indication of the meter multiplied by the constant of the meter and also multiplied by the accuracy coefficient of the meter as determined by the accuracy tests last made and agreed to by the technical staffs of both parties jointly in respect of such meter.

The air meter used by the power company is of the Venturi type, while that used by the consumer is of the swinging-gate type. The former was described in Mr. Hadley's paper.*

The gate type of air meter consists essentially of a weighted door or "gate," swinging from the top on horizontal pivots within a section of the main air pipe. The motion of the gate, the angular position of which is a measure of the flow of air, is transmitted through bevel gearing to a vertical spindle which is connected to the external counter mechanism. This is similar to that used for the Venturi meter, and is described in Mr. Hadley's paper. It contains automatic temperature and pressure correcting cams, and the indications of the dials are given direct in air units.

The "gate" meter has a much wider range than the Venturi meter, and will read with accuracy down to 2 per cent of the full flow. The Venturi meter is not accurate below 10 per cent of the full flow. Both the Venturi and the gate meters were designed by Mr. J. L. Hodgson, of Messrs. Geo. Kent, Ltd., and were first made for the Rand Mines Power Company, Ltd., and Rand Mines, Ltd.

All electric and air meters are open for the inspection of each of the parties, or their authorized agents, and all questions regarding types of meters to be used are settled between the representatives of Rand Mines, Ltd., and of the power company.

Electric meters are tested *in situ* where necessary by means of portable secondary standard meters, the property of the power company, which have previously been tested against the primary standard instruments of the power company in its laboratory. In any instance where it is agreed between the parties that a test *in situ* will not be satisfactory, the meters are tested in the laboratory of the power company.

All testing of electric meters and all testing of portable secondary standard meters against the primary standard instruments are carried out in the presence and to the approval of a representative of Rand Mines, Ltd., and a representative of the power company, and the fees charged by the power company for the use of its primary or secondary standard instruments and other apparatus are agreed between Rand Mines, Ltd., and the power company.

Air meters are, where possible, tested *in situ* by means of portable secondary standard instruments, the property of Rand Mines, Ltd., which have been approved by both parties and previously tested against the primary standard instruments erected at Ferreira Deep, Ltd.

The large displacement air meter, belonging to Rand Mines, Ltd., which is used in the air-testing station at Ferreira Deep, Ltd., is described in Mr. Hadley's paper. It is in constant use, and has proved itself to be a most reliable, accurate, and effective apparatus.

In any instance where it is agreed between the parties that a test *in situ* will not be satisfactory, the meters are tested by comparison with the primary standard instruments at Ferreira Deep, Ltd.

All testing of air meters with the secondary or primary standards is carried out in the presence, and to the approval of a representative of Rand Mines, Ltd., and a representative of the power company; and the fees charged by Rand Mines, Ltd., for the use of the standard instruments at Ferreira Deep, Ltd., are agreed between Rand Mines, Ltd., and the power company.

If at any time during the continuance of the contract either party wishes to change the procedure for testing electric and/or air meters, it has to make representations to the other party, and should there be any difference of opinion, or disagreement, as to the types of meters to be used, or as to the results of the testing of any meters, or as to the procedure to be adopted in testing meters, or as to the fees to be paid, the matter has forthwith to be referred to a local engineer to be mutually agreed upon, or, failing agreement, to the arbitration of three local engineers, one appointed by each party and an umpire named by the two

* *Journal I.E.E.*, vol. 51, p. 24, 1913.

[illegible]

The Use of Electrical Energy on the Mines

With [illegible]

Winders ...	[illegible]	h.p.
Pumps	30,330	,,
Stamp Mills	[illegible]	
Compressors	[illegible]	
Tube Mills ...	10,170	,,
Hauling and Conveying ...	5,290	,,
Crushers ...	[illegible]	
Workshops	2,110	,,
Ventilating	[illegible]	
Miscellaneous	[illegible]	
Total ...	142,300	h.p.

[illegible] group in the following manner:—

Modder "B"	10,130	h.p.
New Modder	13,950	,,
Rose Deep	[illegible]	
Geldenhuis Deep	10,700	,,
Nourse	[illegible]	
City Deep ...	[illegible]	
Village Deep	11,350	,,
Fordsburg Yard (Workshops)	[illegible]	
Village Main Reef	[illegible]	
Ferreira Deep	[illegible]	
Robinson ...	[illegible]	
Crown	38,930	,,
Bantjes	[illegible]	
Durban Roodepoort Deep	4,690	,,
Total	142,300	h.p.

Electric Winders

The most important service is that of winding, as not only is the output of the mines entirely dependent upon it, [illegible] coloured) who descend and ascend the shafts daily. There [illegible] lower depths, in addition to surface winders.

[illegible] Shaft, Village Deep, Ltd., which is 4,144 ft. deep in the vertical. [illegible] zontal, and will probably be served by two winders on different levels, in addition to the surface winder which deals with the vertical only.

[illegible] in the vertical, and 3,267 ft. long [illegible]

No. 2 Shaft, City Deep, Ltd., is 3,328 ft. deep in the vertical, and an incline of over 6,000 ft. long is now being [illegible] has separate winders for the vertical and incline portions.

[illegible] or on order, as enumerated in the table on page 614. The figures do not include small winches, etc.

[illegible] outlay, as is indicated in a paper by Mr. H. J. S. Heather,* [illegible] investigated.

[illegible]

"I am responsible, under Mr. [illegible] ing [illegible] outputs (on [illegible] several are already running. They [illegible] with reverse currents to brake and pull up [illegible]

* H. J. S. Heather, [illegible]

loads, and so far with entirely satisfactory results. I have never worked out the actual saving in capital outlay that has been secured by using induction motors instead of the Ward Leonard arrangement, but I do not think it can be under £50,000." Again, on page 646, Mr. Heather says: "The induction motor is the cheaper system. This was of considerable importance in the case I had to undertake, where capital expenditure had to be kept down."

Such a saving as is indicated above is certainly worth having if there are no serious practical disadvantages from the operating point of view, and, generally speaking, it must be admitted that the 3-phase winding motors on the Rand are working quite satisfactorily. Whether their use is justified, however, under all conditions, and whether Ward Leonard sets would not have proved more economical in working in many cases, are debatable points.

Type	Surface				Underground				Totals
	New		Converted		New		Converted		
	Direct-coupled	Geared	Direct-coupled	Geared	Direct-coupled	Geared	Direct-coupled	Geared	
Ward Leonard	7	—	—	—	—	1	1	—	9
3-phase	2	4	10	31	—	8	—	5	60
Totals	9	4	10	31	—	9	1	5	69
	13		41		9		6		

A 3-phase winding motor *per se* is a much simpler machine than a continuous-current winding motor, with its necessary adjunct on a 3-phase system of supply, the motor-generator, but its control is not nearly so simple.

The control apparatus, as usually supplied, will be familiar to most engineers, so it need not be described in great detail. It consists essentially of:—

(*a*) Stator reversing switches, operated by the first motion in either direction of the driver's control lever.

(*b*) A variable rotor resistance, controlled by the further motion in either direction of the lever.

The rotor resistance usually comprises a tank in which are suspended metallic electrodes connected to the three slip-rings. One side of the tank is closed by a moving weir or shutter, so that the level of the electrolyte, which is circulated by a small centrifugal pump, can be raised or lowered at will, thus varying the resistance across the slip-rings accordingly. The rate of rising of the electrolyte, and therefore the acceleration of the winder, are independent of the driver, being determined only by the rate of delivery of the pump, which is adjustable. This is apparently, and actually, much simpler than the complicated resistances, switches, and connections required by the Ward Leonard system. In practical operation, however, the Ward Leonard winder is much the easier to control, and for the following reasons:—

(*a*) The manual energy required to operate the control lever is much less. In the Ward Leonard system there is only a cylindrical or face-plate resistance switch to rotate, which has no appreciable weight or inertia to overcome.

In the ordinary 3-phase control there is the heavy weight of the weir to move up and down, and, although it may be balanced by external or internal weights, all the masses have to be put into motion and stopped by the driver every time. This is not only very tiring, but militates against accurate or fine adjustments of the position of the weir.

(*b*) In the Ward Leonard system the winding motor can be converted into a generator for braking, by bringing the control lever back just sufficient to lower the voltage of the generator (of the motor-generator set) below the back electromotive force of the motor.

In the 3-phase system the control lever has to be brought back beyond the neutral point, before braking (by reverse current) is obtained. That is (1) the weir and electrolyte have to be lowered, (2) the stator switches opened, (3) the stator switches closed again for the reverse direction, and (4) the weir and electrolyte raised.

(*c*) It is much easier to move the skip or cage of a Ward Leonard winder for a few inches (as is frequently necessary when coming to the landing place or tip) than to do the same with a 3-phase winder, for the reasons given in (*a*) and (*b*) above.

The above features are obvious to anyone who has ever handled both types of winders, and appeal strongly to the drivers.

Attempts have been made to relieve the driver of the manual labour required to operate the control lever of a 3-phase winder, by using electricity or compressed air for opening and closing the stator switches, and compressed air for raising and lowering the weir. So far as the stator

[illegible]

Eddy currents are set up in the face of the ring when the [illegible]

[illegible] Deep, Ltd.

[illegible] setting up insulation strains, and the arrangement has recently been altered by employing a separate motor-generator for each brake, with a rheostat in the field of the generator, so that the main circuit is never broken. [illegible]

[illegible] 1,750 feet per minute, which is half the normal running rope speed for the winders in question. In practice it has been found that the brake will do much more than this, as, [illegible] be brought down to 250 feet per minute, with an expendi- [illegible] will then stop the winder in a few seconds. To obtain an equivalent result by applying reverse current to the [illegible]

[illegible] (with the motor-generator, etc.) to nearly two-thirds of the [illegible]

[illegible]

[illegible]

[illegible] two principal ones peculiar to 3-phase winding motors may [illegible] and only started and stopped say once per day or week [illegible] frequently.

Some makers do not pay nearly enoug[illegible] the stator, so much so that the radial [illegible]

has had to be ground down, and radial stiffening arms made for the stator. Deep frames of box section, with heavy external or internal stiffening rings, are absolutely essential.

The second trouble relates to the rotor slip-rings and the control gear. If a 3-phase motor is running at full speed and reverse current at full pressure is applied to the stator, the induced open-circuit standstill rotor voltage is doubled. Many of the 3-phase winding motors on the Rand have an open-circuit standstill pressure of 750 volts, so that in such cases the application of reverse current at full speed, with the rotor on open circuit, would give a rotor pressure of 1,500 volts.

To avoid working with an open rotor circuit at any time, a sill is arranged at the bottom of the weir opening in the control tank, so that the tips of the electrodes are always immersed, but even with this a high rotor voltage is always obtained.

Manufacturers of 3-phase motors do not always provide sufficient insulation between the rotor slip-rings, between the slip-rings and the shaft, and between the brush holders, even for the full open-circuit standstill rotor voltage, if kept on for any length of time. The idea apparently is that, as the motors are run with the slip-rings short-circuited, the insulation is therefore of no great importance. Unless the insulation of those parts of such motors is kept scrupulously clean, trouble is often experienced in starting up.

With 3-phase winder motors this point is even more important, not only because such motors are started and reversed frequently for many hours together, but also because of the higher rotor voltage obtained when reverse current is applied.

The rotor resistance tanks which were originally supplied with the large majority of the 3-phase winders gave considerable trouble, because they were too small for the required duty and the electrodes were arranged much too closely together, a spacing of about $\frac{3}{4}$ inch between phases being common.

During straight winding operations no great difficulties were experienced, but flash-overs between the electrodes were frequent when reverse current was applied, and even when these did not occur the electrolyte soon reached too high a temperature, as the retarding losses were then added to the accelerating and winding losses. As soon as a flash-over takes place the automatic circuit-breaker opens and cuts the winding motor off the supply circuit, leaving only the mechanical brakes for stopping the winder.

The capacities of a number of the tanks were afterwards increased and the disposition of the electrodes altered. This has been quite effective in removing the risks of flashing over, but the resistance at full load is somewhat high, which not only wastes energy, but causes a comparatively high rotor "slip."

Some experiments were then made to determine the safe minimum distance apart between phases, so as to avoid any chance of flashing over. The following were the results obtained, viz. :—

	Distance apart of Electrodes	Flash-over Voltage	Water Temperature
(1)	$\frac{1}{2}$ in.	750/800	186° F.
(2)	$\frac{3}{4}$	850/900	188°
(3)	1	680	185°
(4)	$1\frac{1}{2}$ in.	1,300/1,400	— F.
(5)	2	1,500	200°
(6)	$2\frac{1}{2}$	1,620	200°
(7)	3	No flash-over up to 1,800 volts	200°

N.B.—Ordinary water, without added salts or acids, was used for the electrolyte, and the lower edges of the plates were just touching the surface, except in No. (3), when the plates were immersed $2\frac{1}{2}$ inches.

It would be impracticable to arrange all the electrodes with no less distance than 3 inches between them, as the sizes of the electrodes and tanks would have to be very great in order to give a sufficiently low resistance at full load and speed, when the electrodes are fully immersed. As, however, the rotor voltage decreases to practically zero as the rotor attains full speed, and from twice the normal to less than normal as the winder and its load are gradually brought to rest by reverse current, it follows that the proper arrangement is to use electrodes of such varying shapes and lengths that the distances apart of those portions of the plates of the three phases actually within the electrolyte are gradually reduced as the electrolyte rises, and that the increase in the areas of the immersed portions of the plates is such that the current density is kept at a low value. A density not exceeding 1 ampere per square inch has been found to be a safe limit.

In other words, if the immersed portions of the electrodes are far enough apart and of such areas as will always keep the current density at a value not greater than the figure given, it will be found that they will be close together and of large area at full immersion when the rotor voltage is low and the current high ; and at a safe distance apart and of small area when the rotor voltage is high and the current low.

Various designs of flat-plate electrodes were tried with this object in view, but they all proved more or less impracticable. The experiment was then made of using a large number of rods (actually angle iron) of varying lengths, arranged in the tank so that their disposition could be easily changed to obtain the required result. This was successful, as no flashing-over was observed under working conditions, and the increases and decreases of areas and resistances were quite satisfactory.

It has been suggested that two resistance tanks could be used, one for winding and the other for reverse-current braking. While no doubt this would be successful from the tank and electrode point of view, it would involve special control lever arrangements and interlocked change-over rotor switches, besides considerably increasing the cost. Designs for such an arrangement have been worked out, and it would certainly remove one danger which exists with the ordinary single-tank apparatus.

In cases of emergency it is difficult to prevent the driver of a 3-phase winder from bringing his operating lever very quickly back to the reverse position, and as the electrolyte in the full tank takes an appreciable time to fall, and as the driver may have again raised the weir before the tank is emptied, there is the risk that the reverse stator switches will be closed with the electrodes sufficiently immersed to give a comparatively low resistance while the

[illegible]

The general arrangement of the apparatus is as follows:—

(1) [illegible]

(2) [illegible]

(3) [illegible]

(4) [illegible] automatically controlled by a relay system in the rotor circuit, so that, although the control lever may be put right over at the start, no succeeding rotor switch closes until the rotor current, which has increased on the closing of the preceding rotor switch, has fallen to a predetermined and adjustable amount.

The advantages claimed for this method of control were:—

(a) No heavy work is imposed on the driver in operating the control lever.

(b) No energy is wasted in continually pumping electrolyte.

(c) The full speed of the motor is obtained, as, when the last rotor switch closes, the rotor is metallically [illegible]

(d) No energy is wasted in the rotor resistance during the period of full-speed running, but only during the periods of acceleration and retardation.

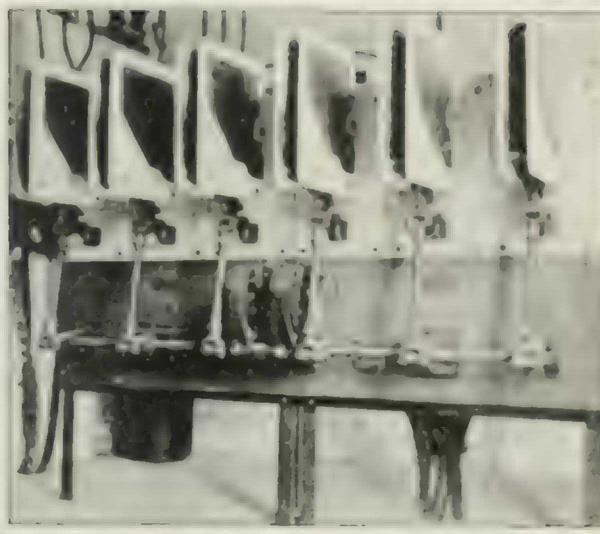
(e) There is no possible risk of flashing over, however quickly the control lever is operated.

(f) There is no cooling pipe system to be kept clean and in order.

[illegible] at the Village Main Reef, Ltd., and was used with great [illegible] follows:—

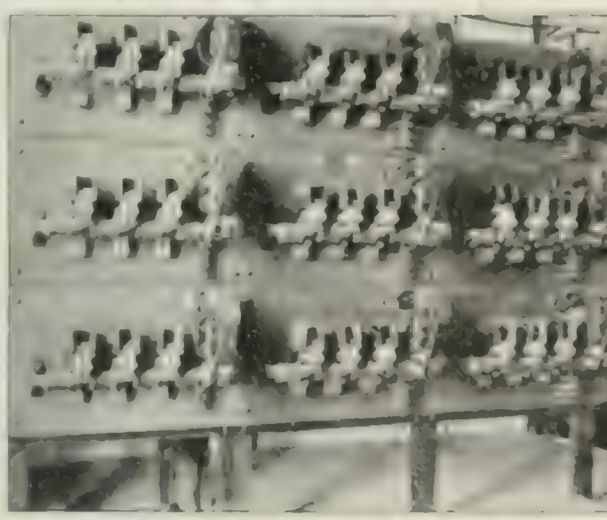
(1) [illegible] on the light wooden floor of the engine-room. The [illegible] floor.

(2) [illegible]



[illegible]

[illegible] outside the engine-room, and to [illegible]



[illegible]

[illegible] appears to be quite [illegible]

Fig. 2 shows the stator contactor switches and Fig. 3 the rotor contactor switches. It is in successful daily operation at the Village Main Reef G. M. Company, Ltd. Although a little more expensive in prime cost than the ordinary type of liquid control, this is more than repaid by the effectiveness and the saving of the heavy losses in the rotor resistance during the times of full-speed running.

With a view of obtaining competitive arrangements, the author, in July 1914, sent particulars of the contactor-relay system of control to a British firm which claims to be expert in that class of work. It took nearly 5 months for a reply, other than an acknowledgment, to be received, and then the information sent was entirely useless. Wake up, England !

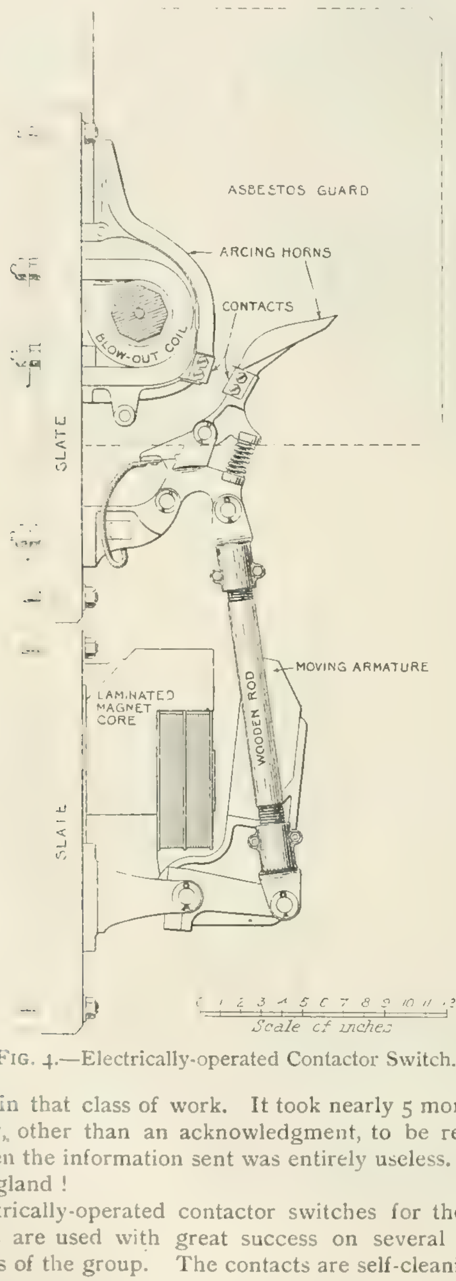


FIG. 4.—Electrically-operated Contactor Switch.

Electrically-operated contactor switches for the stator circuits are used with great success on several 3-phase winders of the group. The contacts are self-cleaning and are broken under a magnetic blow-out, and the maintenance is exceedingly small when compared with the ordinary pattern of oil switch. A contactor switch is shown in Fig. 4, from which its essential parts will be seen.

Manufacturers do not seem to realize the nature of the duties which winder oil-break switches have to perform, and they usually supply the ordinary switchboard type. While the latter is only called upon to open and close feeder or machine circuits occasionally, and generally with no load on at the time, switches for 3-phase winders frequently have to make and break circuits from 500 to 1,000 times per day, and the breaking is usually done under full load. It requires a very substantial switch to stand up to this sort of work, and the arcing contacts and the oil have to be renewed at least once a week. This is a very "messy" and expensive job, and contactor switches are being insisted upon for all future 3-phase winders. On a 3-phase winder at Rose Deep, Ltd., these switches have made and broken the stator circuits over 388,000 times without any cost whatsoever for repairs or maintenance.

The author has endeavoured to obtain from his own experience reliable comparative figures of the costs of Ward Leonard and 3-phase winders, but the weights raised, rates of acceleration, speeds of winding, and depths of shafts are so variable on the mines of the group which have the two classes of winders, that he cannot put forward data of any real value. It may be stated generally that the deeper the shaft (*i.e.* the longer the relative period of full-speed winding) the cheaper is the 3-phase system compared with the Ward Leonard, particularly if the contactor system of rotor control is used, because with the latter the resistance losses are entirely eliminated at full speed.

With balanced (double drum) winders working without a tail rope, there is, however, a limit to the depth at which a 3-phase winder is the more economical, because the weight of the descending rope ultimately overbalances the weight of the ascending load and reverse current has to be applied to prevent the winder running away. Such energy has to be paid for, but with the Ward Leonard winder the greater part of the braking energy can be returned to the line. There is therefore not only the saving of a loss, but a distinct gain to be made.

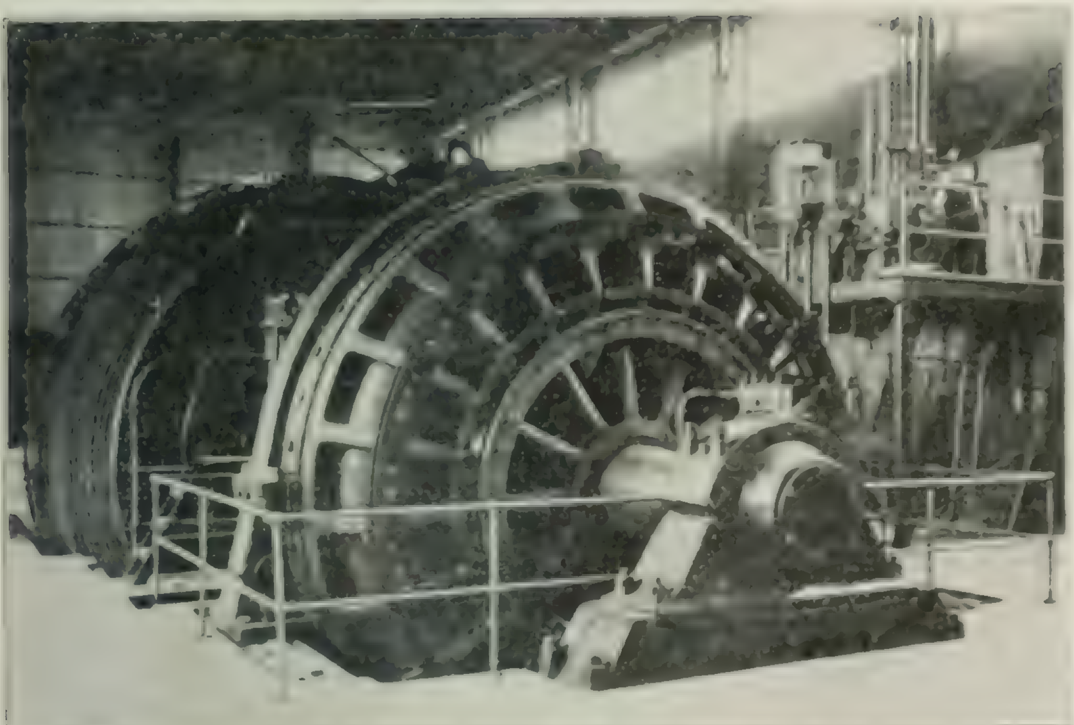
For a winder which is frequently or constantly used for lowering loads, such as men or material, or, in some cases of incline shafts, lowering rock to a point where it can be better raised by a vertical shaft winder, the Ward Leonard system is much to be preferred.

It is only by drawing out a diagram for each individual case that a proper decision can be made as to which type of winder is the correct one to employ.

One advantage which the 3-phase winder has over the Ward Leonard is that geared motors running at 375 r.p.m., or at higher speeds, can be most conveniently employed in the majority of cases, which not only means a much cheaper equipment, but a better and more economical motor than if a direct-coupled one were used. With the Ward Leonard system a direct-coupled low-speed motor, although more expensive, gives a better working machine.

Fig. 5 shows the largest electric winder in South Africa. It is of the Ward Leonard type and has two motors, each of 2,000 h.p. (R.M.S. rating), one at each end of the drum shaft. There are two cylindro-conical drums, each 22 ft. diameter, which wind a net load of 16,000 lb. from a depth of 3,540 feet at a speed of 3,500 feet per minute. The winding ropes are 2 in. diameter. This winder is one of three at the South Rand shaft of Crown Mines, Ltd., and they operate at 54 r.p.m.

[illegible]



[illegible]

[illegible]

[illegible] brought from the working levels right to the surface in [illegible] are landed from the cages at the collar of the [illegible] on the cages and the headgear sheaves.

[illegible] rather than avoided. The ore is brought to the surface in [illegible]

[illegible] Rand have been caused, not by any failure to stop the skip, [illegible] pulled into the headgear sheaves before the winder drum has made half a turn.

[illegible] driver must retain full command of the winder, in whatever position the skip is, to be able to bring the skip to the exact tipping point. This operation frequently calls for slight movements of the winder after it has first been stopped.

[illegible] Simmer and Jack East mine, near Johannesburg the inven- [illegible]

he attempted to start the winder in the wrong direction with the skip in the tip, without in any way taking away from him the full command of the winder. On investigation this claim was found to be fully justified, and since that date the whole of the winders on the mines of the group have been fitted with the Philip's device. Its principle is illustrated in Fig. 6, which shows a diagrammatic arrangement, and the action is as follows :—

A 2-way controller switch is connected to the driver's operating lever, so that the contacts are open when the lever is in the neutral or "off" position. A slight motion of the lever in either direction closes the contacts on one side or the other. An insulated disk, with a short metallic insertion on the edge, is fixed on the spindle of each depth indicator dial, with two contacts arranged so that the

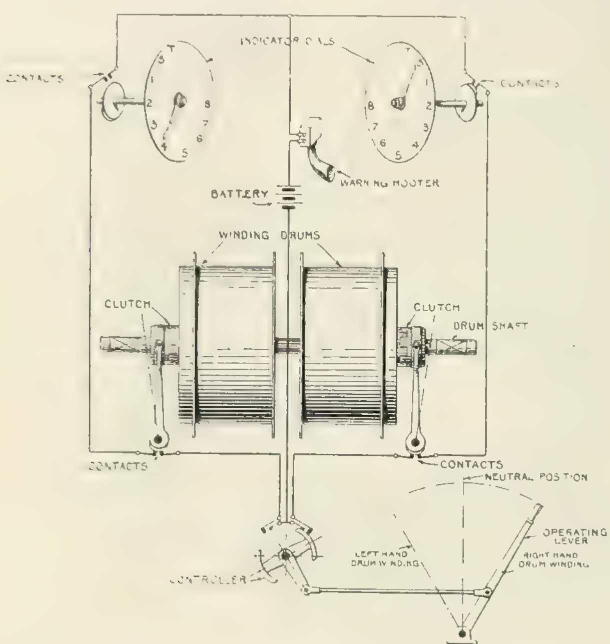


FIG. 6.—Diagram of Philip's Indicating Device.

circuit is closed when the depth indicator shows the skip to be anywhere in the region between the headgear sheaves and, say, 150 feet below the collar of the shaft.

A battery and a loud warning hooter complete the apparatus, which is connected up as shown in Fig. 6. In the case of winders with loose drums operated through clutches (a great many of these winders are in use on the Rand to wind from different levels) an auxiliary contact is provided which is broken when the clutch is open and the brakes are holding that drum.

By following through the connections it will be seen that when a skip is within what may be called the "danger zone" the smallest movement of the operating lever in the direction to raise the skip will sound the hooter, which is placed close to the driver. He is at once warned, and unless he has deliberately put his lever into that position he quickly pulls it back before any damage has been done. He can only raise the skip within the danger zone with the full knowledge of what he is doing, and he is also warned by the hooter if he keeps the power on past the pre-determined point in the shaft. This simple apparatus has already been the means of preventing a great many accidents.

There are many designs of overwinding devices, both electrical and mechanical, which come into operation when the skip has passed a certain point in the shaft or headgear and stop the winder by cutting off the power and applying the brakes. Some act through a centrifugal governor and prevent the driver from winding at too great a speed within the danger zone. Others only act when the skip has actually come to a few feet above the correct stopping place. One of the most common and effective types employs cams or screws with running nuts gradually to bring the control lever back to the off position if the driver has not already done so.

Depth Indicators.

The most general form of depth indicator used on winders on the Rand is that of the dial pattern, as indicated in Fig. 6, and of which a part back view may be seen in Fig. 1. The dials are usually about 5 ft. diameter, and are mounted on high cast-iron pillars, placed one at the right hand and one at the left hand, either in front of or behind the winding drums, facing the driver's platform.

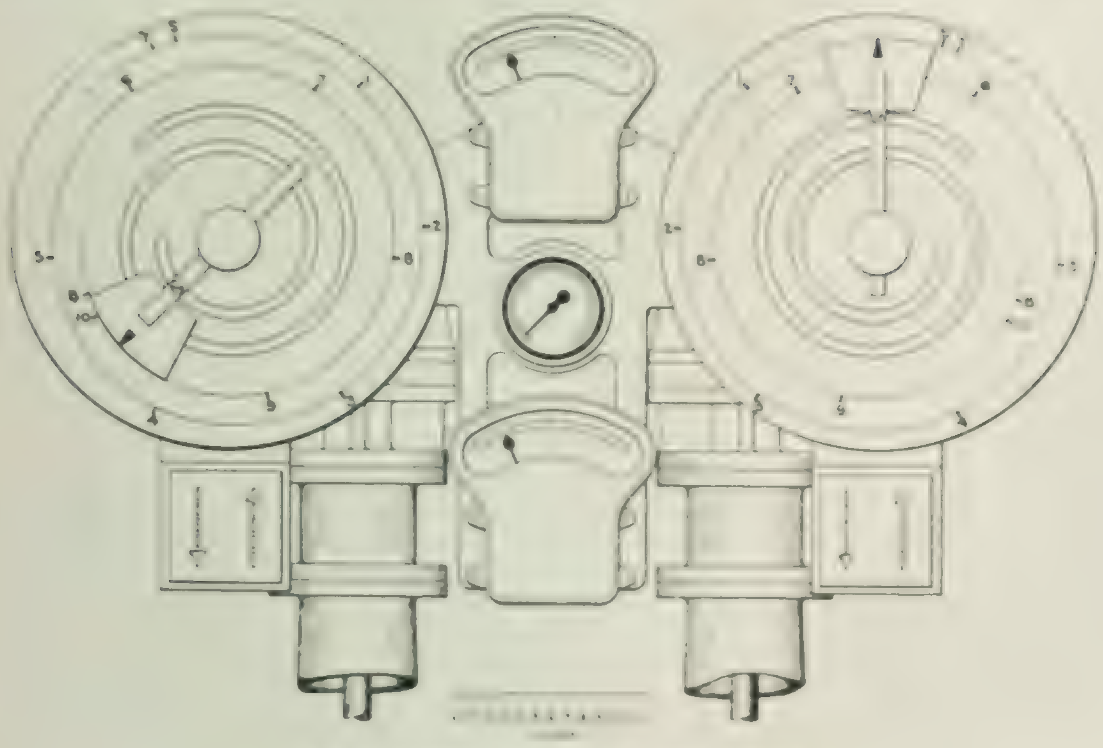
When the old steam winders were converted to electric driving the original depth indicators were kept in use, and the electrical instruments, being of a small size, had to be mounted on or close to the driver's platform so that they could readily be seen. Even for new electric winders the same arrangement of large depth indicators at a distance and small electrical instruments close to the driver was retained. Only in a few cases has the vertical screw pattern of indicator been used, still with the electrical instruments mounted separately.

It appeared to the author that it was a wrong principle to make the driver have to watch two sets of indicators, one mechanical and one electrical, in such different positions and at such different distances, and that the eye strain must be detrimental. He therefore endeavoured to bring all the indicators to one place, namely at a distance of about 6 feet in front of the driver, and to reduce the size of the dial of each depth indicator so that it would have the same angular diameter as at the greater distance. For example, a dial 5 ft. diameter, at a distance of 20 feet, would appear no larger than one 18 in. diameter at a distance of 6 feet. It is obvious, also, that as the angular movement of the pointer would be the same whatever the diameter of the dial, the indications would be just as visible on the smaller dial at the reduced distance, as on the larger dial at the original distance.

Owing, however, to a recent (1914) requirement of the Transvaal Government Mines Department, that the tip of the pointer of the indicator should have a movement of not less than 1 inch for each complete revolution of the winding drum, a dial 18 inches in diameter was found to be too small for most of the winders, as with an 8 ft. winding drum it would only indicate to a depth of about 1,000 feet.

The Government requirement was based upon the practice of the drivers, viz. to watch for rope or drum marks during the last revolution of the drum, to guide them in bringing the skip to the correct spot, and, with a pointer movement of less than 1 inch per revolution, it was considered difficult to determine when the last revolution had arrived. This restriction makes the vertical-

[illegible]



[illegible]

[illegible] groove at the front end of the pointer spindle, and is guided in its circular motion by a small roller on the under- [illegible]

[illegible] This, with only an 8 ft. diameter drum, will serve for a depth of 2,900 feet, on the basis of 1 inch of movement for each revolution of the drum.

[illegible] plete indicator set is mounted on two pillars immediately in front of the driver's platform, with the tops of the dials at a height of about 4 feet above the platform

(green) under the right-hand dial are illuminated. The reverse action takes place when the skip in the right-hand [illegible] which has the red arrow under it.

[illegible]

[illegible] done either by Cornish pumps, steam operated from the [illegible]

water by stages into sumps, from which the next higher pumps drew their supply.

The next step was to eliminate the Cornish pump and to use motor-driven geared ram pumps for heads up to between 2,000 and 3,000 feet. This continued to be the common practice until 1912, when, on the advice of the engineers of the group, it was decided to use high-speed, multi-stage centrifugal pumps, with direct-coupled motors, at the South Rand shaft of the Crown Mines, Ltd., and at No. 1 Shaft, Durban Roodepoort Deep, Ltd. The plant at both mines is identical, and each consists at present of two pumping units. Each unit comprises a high- and low-pressure 8-stage Sulzer pump, with the motor arranged between the two pumps, and lifts 375 gallons of water per minute to a height of 2,400 feet. The sets run at 1,470 r.p.m. and take about 500 b.h.p.

A little trouble was experienced at first owing to the nature of the water, which was slightly acid and contained a large amount of finely-powdered rock in suspension. A scheme of settling sumps was then arranged, in which the acidity of the water is removed by lime treatment and the suspended matter is allowed to settle. Since these sumps have been provided the plant has worked with great success, and is now being extended at Crown Mines, Ltd., by units of twice the size.

The reduction in working costs over the original ram pumps has been very marked, and is sufficient to wipe off the whole of the new capital outlay in about two years. It is not that the centrifugal pump, by itself, has a higher efficiency than the ram pump, but the use of the former renders concentration of large, high-power, and high-speed pumping units possible in a minimum of space, with a minimum of attention and very low maintenance costs.

The success of the centrifugal pumping system has been such that large similar schemes are now being considered for other mines of the group.

The importance of reliable underground mining pumps, and particularly of the electric supply to the motors of such pumps, cannot be over-estimated. A stoppage of less than 24 hours would be sufficient in some cases to flood the lower levels of the mines, which would not only drown out the pump chambers, but involve bailing in the shafts by means of tubs and the winding plant before the pump chambers could again be entered. For the lowest level of the South Rand Shaft of Crown Mines, Ltd., the pump motors will be operated at 200 volts from oil-immersed transformers, and the rotors will be of the squirrel-cage type. They will be started with the primary windings of the transformers connected in star, which will be changed over to mesh connection when full speed is reached. The object of this is to render the motors less liable to break-down should the pump chamber become flooded. There will be no switches between the transformers and the motors.

The other classes of pumps used on the mines, such as slimes pumps, sands pumps, small water pumps, etc., are generally electrically driven by belts. Nearly all the motors are of the slip-ring type, in which the rings are short-circuited and the brushes lifted at full speed. Belt driving has been found to have many advantages over direct coupling, as the pumps are often in positions, such as pits which are liable to be flooded, where a motor could not be placed, and, owing to the increases in the reduction plants from time to time, it is very convenient to be able to alter the speeds and lifts of the pumps merely by altering the sizes of the pulleys.

Mill Driving.

After the ore is tipped into the headgear bins it is rough sorted by being carried over long and wide rubber belts, where the waste rock is removed by hand as far as is practicable. It is then passed into crushers, both the jaw and rotatory types being used, in which it is crushed to pieces of $1\frac{1}{2}$ in. cube and smaller. The methods of driving the sorting belts and crushers call for no special mention, excepting that, as the belts travel at a very low speed (about 40 feet per minute), high reduction gear has to be used.

The ore is then taken to the stamp mill, which is a feature of all gold mines, where it is further crushed to fine particles. The Californian type of stamp is in universal use. It consists of a circular steel weight, about 9 in. diameter, and 4 ft. long, fixed at the lower end of a steel rod called the "stem." The rod and its stamp are lifted by means of a cam, which, by rotating, engages on the underside of a tappet on the stem, lifts it for a distance of about 8 inches, and then allows the whole to fall by gravity on to a steel block at the bottom. Double-armed cams are employed, and the stamps are generally set in blocks of five or ten, and worked from a common cam shaft, the cams being arranged so that the stamps fall, one after the other, in a regular sequence. The ore is fed with water under the stamps, which weigh from 1,200 to 2,000 lb. each. Fig. 8 shows the general arrangement of a mill.

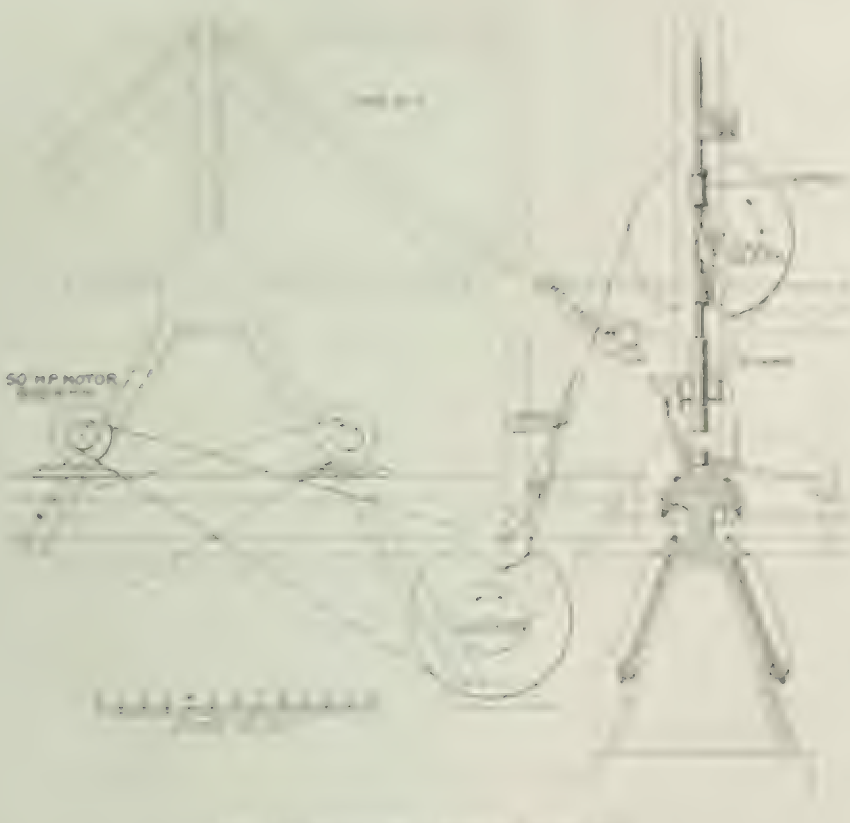
The cam shafts of the different stamp groups are driven by belts—(*a*) in the older types of mills from a common line shaft to which the motor is belted, one large motor frequently driving from 80 to 100 stamps, and (*b*) in the newer mills from a separate motor to each group of 10 stamps. Each stamp requires 5 h.p. on the average.

The whole of the work is done by the motors in lifting the stamps, and is therefore the same whether any rock is being crushed or not. As the stamps fall by gravity the speed of dropping depends only upon the weight of the stamp and the height to which it is lifted. It will be evident that there must be a limiting speed for the rotation of the cam shaft, as if it be rotated at too high a speed there will be a danger of the uprising cam meeting the descending tappet before the latter has completed its fall, with the great risk of either breaking the cam or the cam shaft. Such an effect is called "camming," and experience has shown that this danger exists at greater than 98 drops per minute, and it increases of course with any increase in the speed of dropping.

Having fixed the output of the stamp mill on the basis of 98 drops per minute for each working stamp, while any increase in the speed is dangerous any decrease will reduce the output of the mill in the same proportion. A constant rate of speed for the driving motors thus becomes imperative. This, unfortunately, is in the control of the power company, and is determined solely by the frequency of the electrical supply.

The limits of frequency laid down in the contract are

[illegible]



[illegible]

[illegible] illustration, and therefore the cam shafts revolve at only [illegible] 7 ft. 2 in. diameter, and even with this the belt speed is [illegible] used, with a jockey pulley to keep them tight, owing to [illegible] the angular velocity having been doubled, and the vibra- [illegible] much increased that the experiment had to be abandoned.

[illegible] pleted in the stamp mill by [illegible] until it was small enough to [illegible]

plant is considerably increased and a much finer product is obtained. The gold particles, being so extremely small, cannot all be extracted unless the ore is crushed or ground to a powder.

The tube mill is a cylindrical steel vessel, like a boiler shell, a common size being about 22 ft. long × 5 ft. 6 in. diameter. It is carried upon hollow trunnions and is rotated at a speed of about 28 r.p.m. The interior is lined either with hard segmental stone blocks or with concrete in which steel pins are embedded. The crushed ore as it comes from the stamp mill in the form of a coarse pulp is fed through the trunnion at one end, together with a number of small selected pieces of ore, called pebbles, about 3 in. cube, which act as grinders, and themselves gradually become reduced to a powder. The finished product comes out of the trunnion at the other end, and is then ready for passing over the amalgam tables.

If the action of the tube mill be carefully considered, it will be found that there is a critical speed at which it should revolve to get the best results. Imagine the mill rotated at a high speed. In such a case the centrifugal action would throw the pulp and pebbles against the inside of the mill all round, and there they would remain and rotate with it without being ground in any way. Now let the mill be rotated at a very low speed. The whole of the material inside would merely slide and would remain practically at the bottom of the mill without any useful work being done. At the correct speed of rotation the material would be carried about half-way round and would then fall perpendicularly to the bottom, thus giving the maximum mixing and grinding effects.

It follows from the above reasoning that there is also a correct level to which the tube mill should be filled to obtain the best effect. This is slightly under half full.

A tube mill takes a considerable amount of energy to start it rotating, as the whole of the weight of the material lies at the bottom. It is also very sensitive to overloading, and many tube mill motors have been burnt out from this cause. Motors of 100 h.p. have been generally used, but these are gradually being replaced by motors of 125 h.p. and 150 h.p. for this reason.

A number of attempts have been made to drive tube mills by direct gearing from the motor shaft, but, so far as the Rand is concerned, with no great success. Motors running at 365 r.p.m were used, with "Citroen" single-reduction gears, consisting of a pinion on the motor shaft and a spur rim bolted on the outside of the tube mill at one end. The gear ratio was about 13 to 1. The end movements of the tube mill were sufficient to do away with all the benefits of the high-class gears, and even with a flexible motor coupling caused great gear wears and trouble at the motors.

While it is possible that a straight toothed gear would have accommodated itself to the end movements of the tube mill, the high gear ratio required rendered its use impracticable.

The present standard practice is to use a motor running at 585 r.p.m., to belt this to a pulley on a pinion shaft running at 120 r.p.m., and to use straight toothed gearing with a ratio of about 4·3 to 1. The mechanical efficiency may be slightly less, but the commercial efficiency is decidedly greater.

The best proportions of diameter and length for the tube mill have not yet been finally determined, but some metallurgists have a decided opinion that the present usual length of the mill (22 ft.) could be considerably reduced with advantage.

Electric Compressors.

It was mentioned, earlier in this paper, that four of the mines in the group do not obtain their supply of compressed air from the air mains of the power company, but that they use electrically-driven compressors on their own property. The equipments are given in the table on this page.

Mine	Converted Rope-driven Compressors					Direct-coupled Compressors				
	No.	r.p.m.	h.p. each motor	Total lb. air per min.	Lb. press. per sq. in.	No.	r.p.m.	h.p. each motor	Total lb. air per min.	Lb. press. per sq. in.
Modder B.... ...	1	78	750	276	80	2	163	1,000	812	100
New Modder ...	—	—	—	—	—	5	163	1,000	2,030	100
						1	247	600	218	100
Bantjes	3	80	550	622	83	1	3,000	560	812	7·5
Durban R.D. ...	—	—	—	—	—	2	247	600	436	100

The rope-driven compressors are all of the horizontal 2-stage type, and in each case have been converted from steam driving by removing the steam pistons and replacing the flywheel by a rope pulley, on to which the motor drives. The direct-coupled compressors are, with the exception of the one at Bantjes, of Messrs. Belliss & Morcom's standard vertical 2-stage pattern.

The direct-coupled compressor at Bantjes is of the high-speed turbine type. It compresses the air up to 7·5 lb. gauge pressure, at which pressure the horizontal rope-driven compressors take it and complete the compression. It was made by Messrs. C. A. Parsons & Co., and has been most successful in operation.

Intercoolers are used between the different stages of all

[illegible]

$$W = [illegible]$$

where W = lb. weight of air flowing per second.

[illegible]

in the proportion which the weight per [illegible] per cubic foot of aqueous vapour in the air entering the compressor. The constant for dry air is taken as 53·22, and the constant [illegible]

For normal atmospheric air on the Rand, [illegible] with a barometric pressure of 24·616 in. of [illegible]

P = pressure on the down-stream side of the orifice in lb. per square inch absolute.

h = difference of pressure between the two sides of the orifice in lb. per square inch (as [illegible]

[illegible]

Under the above conditions the factor $\sqrt{\frac{2g}{R}}$ for normal air on the Rand = 1·0951.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible] great amount of fine dust which [illegible] dry crushing operations. Even [illegible] generally placed in separate houses, the dust manages to find its way through the necessary belt and shaft openings, [illegible] motors and gets into the bearings.

[illegible] withstanding this, it is better practice to use separate motors for each crusher than one larger motor for several crushers, as it not infrequently happens that the maximum crusher loads occur at the same time. There are not [illegible] give anything like a levelling-out of the load.

[illegible]

There is nothing which calls for any mention in the use of electric power for these services.

[illegible]

As a general rule all [illegible] type, and those above of the slip-ring type.

[illegible]

plates in the rotor circuit for starting purposes. The stator is switched directly on to the mains with the plates raised, and they are then gradually lowered until they are short-circuited at the tank. The rings are then short-circuited on the motor and the brushes raised. The usual short-circuiting arrangement is generally so defective that in many cases it has been removed, and the motor run with the brushes always down on the slip-rings.

In order to avoid a high pressure across the slip-rings on starting up, either a small (high value) resistance is connected between the dipping plates, or the level of the liquid is so arranged that the tips of the plates are always immersed.

Maximum-current and no-volt trip coils are used on the oil switches of all slip-ring motors, and of larger squirrel-cage motors which are started by compensators. For small squirrel-cage motors, which are self-starting when the stator is switched on, fuses only are used.

Electric Distribution.

The power company's electric supply is given at normal pressures of 2,100 volts and 525 volts at the consumers' terminals. The distribution switch-houses belonging to the mines are built either at right angles or parallel to the power company's transformer houses, and the supply terminals are brought just through the party wall. In parallel switch-houses the 2,100-volt switchgear is arranged in line at one end and the 525-volt switchgear in the same line at the other end. In right-angled switch-houses the 2,100-volt switchgear is arranged on one side and the 525-volt switchgear on the other, with a common operating passage between them.

The arrangement of the original switchgear was very defective. There were no barriers between the different sets of apparatus, so that any arcing which might accidentally occur, either in a switch, transformer, or isolating link, was most likely to spread to adjacent apparatus. The busbars were quite unprotected, and there was nothing either to prevent the attendant, who might have to enter the passage behind the switchgear, from touching any part, or to save him from falling into the gear.

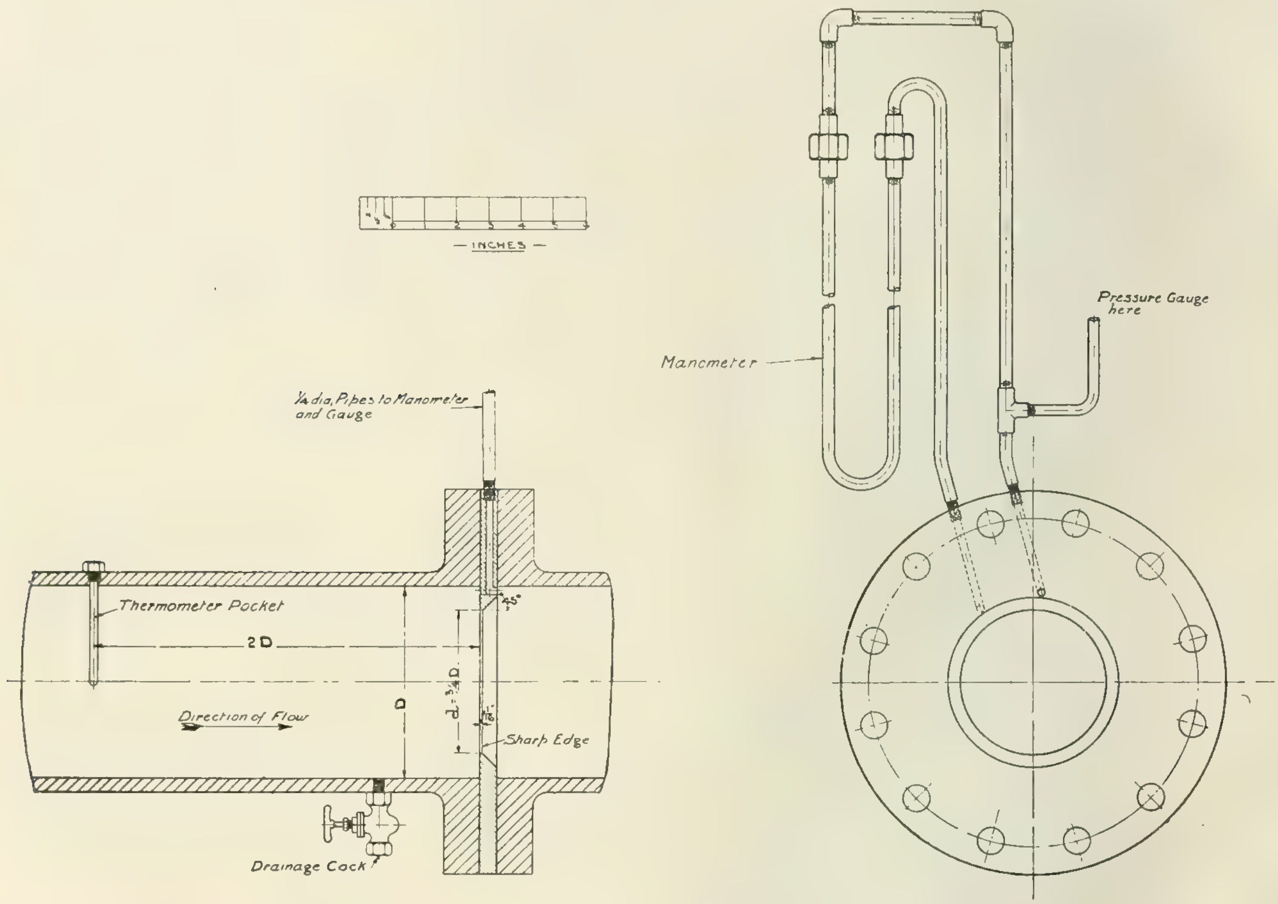
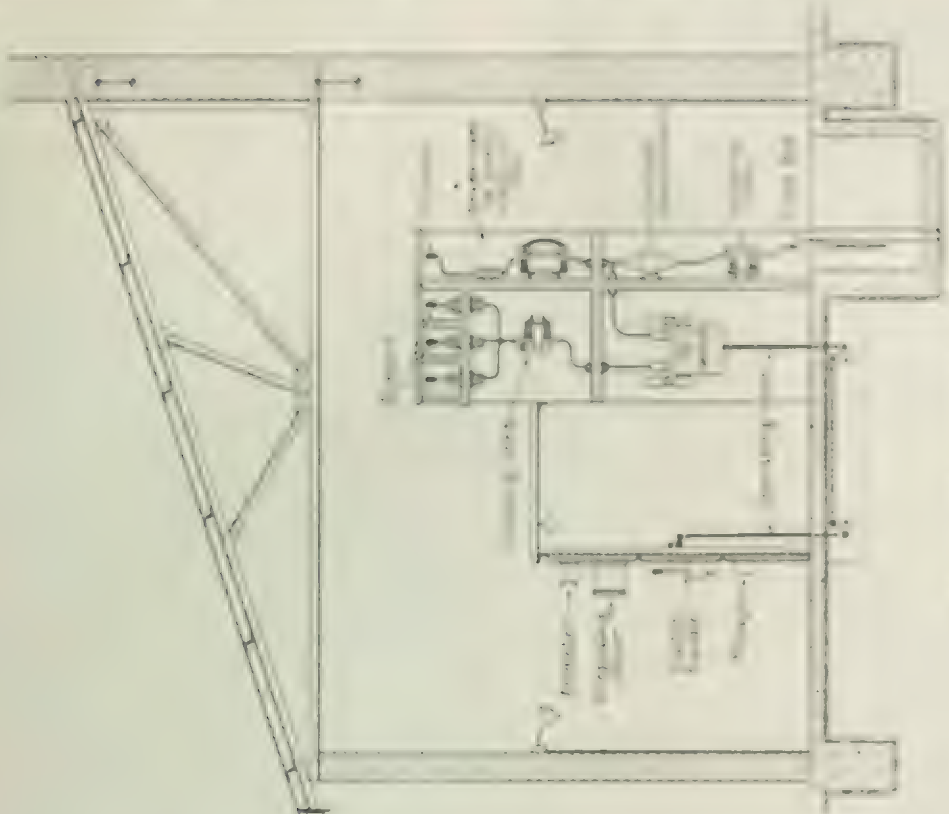
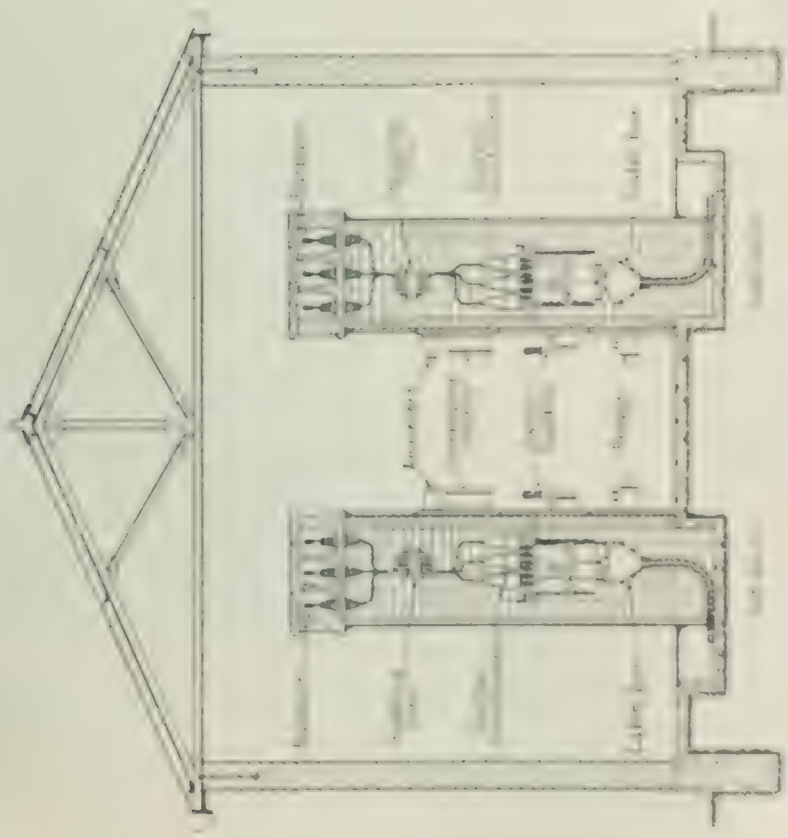


Fig. 9.—Orifice for Air Measurement.

The need was obvious, but the difficulty was to provide a remedy without interrupting the supply. In those switch-houses which had any vacant space, new switchgear was erected at the end, and the circuits changed over one at a time, so that as an old switch section was removed a new one could be built in its place. In other switch-houses an extension to the building had to be made before anything could be done. The whole change-over was a long process, but the result has well repaid for the trouble.

The design of switchgear now in use in the majority of the switch-houses is shown in Fig. 10. The three





busbars are carried in brick compartments at the top, and a separate brick cubicle is provided for each line of switch parts. The front slate panels are 2 ft. wide and contain an ammeter, an integrating watt-hour meter, and the switch control lever with its overload trip coil. No-voltage trip coils are now only used on the local control gear of individual motors. They were provided in the switch-houses on the panels of the original gear, but were soon removed. The openings of the cubicles in the passage way at the back are covered by removable frames of expanded metal.

The latest form of switch-house is built parallel to the sub-station, and Fig. 11 shows the design of switchgear employed. The cubicle arrangement has been developed to provide isolated sections for the different parts of the gear, so as to limit the result of any accident as far as possible. The cubicles are made of reinforced concrete. The new arrangement requires more space, but as the security of the whole supply depends upon the reliability of the switchgear the little extra expense is thoroughly warranted.

The oil switches first used had been provided merely on a current-carrying basis for the full load of the circuit which they were to control. This is a very common but most erroneous practice, because it is so often forgotten that an automatic switch should be able to open the circuit with safety to itself under the worst conditions, which will probably be a short-circuit on the cables just beyond it. Frequent switch failures naturally followed. The rules now are: (*a*) that all oil switches in a switch-house shall be of the same size, (*b*) that such switches shall be rated for a current of 800 amperes at 15,000 volts, and (*c*) that no difference shall be made between the equipment of cubicles for 2,100-volt and 525-volt circuits, except in the current transformers and the meters. Since the above practice was instituted, trouble in switch-houses has practically disappeared.

Three-core, lead-covered and armoured cables, laid in trenches, are universally used between the main switch-house and the various sub-distribution points on each mine. The points are arranged to suit the local conditions, and are generally interconnected so that the failure of any main cable does not stop the supply. Link cages, without switches, are provided at the sub-points, so that the sub-circuits can be isolated at any time and the feeders interconnected as may be required. The largest cable used is of 0·5 sq. in. section per phase, and a separate panel for each feeder cable is provided in the switch-house. Where necessary several cables are run from the switch-house to individual link cages, and are operated in parallel.*

Troubles.

Many and varied troubles have been experienced since the beginning of the power supply, quite apart from those which can be laid to the charge of the power company. They have been very costly in some cases and very annoying in all, and each and every one could have been avoided. The troubles have arisen from two main causes: (*a*) faults in design, and (*b*) faults in manufacture.

* For interesting details regarding cable systems for gold mines, see a paper on "Electrical distribution for mines," by Mr. J. W. Anson, *Transactions of the South African Institute of Electrical Engineers*, vol. 3, p. 191, 1912.

(*a*) *Faults in design.*—The want of stiffness in the stator frame of some 3-phase winding motors has already been mentioned. It has been found both in low-speed direct-coupled motors and in geared motors. The fault is a most serious one and the remedy is obvious.

Some makers secure the stator core stampings by means of dovetailed strips screwed to the inside face of the frame. This is not nearly such good practice as to machine dovetailed slots out of the solid metal of the frame, into which the dovetailed projections of the stampings fit, as there is always the risk of the screwed strips getting loose under the severe racking strains to which the stator of a winding motor is always subject.

A number of 3-phase winding motors were supplied in which the dovetailed strips were "secured" by means of studs with nuts on the outside of the frame within the housing. No lock nuts or even spring washers were provided, and, as the practice of the makers was to adjust the air-gap by means of the studs, the results can be imagined.

In motors by the same maker the stator and rotor core-plates were clamped sideways by bolts passing right through, and the nuts were entirely hidden by the end loops of the coils. One motor was delivered in which the width of the stator core was $18\frac{3}{8}$ inches on one side and only 18 inches on the opposite side, while the corresponding dimensions of the rotor core were $18\frac{1}{8}$ inches and $17\frac{5}{8}$ inches. It was impossible to get at the nuts to tighten up the core-plates without first removing the windings. This may be considered as a fault in manufacture, but had the design been a good one the fault could not have occurred. The proper way to secure core-plates sideways is to clamp them between stiff end plates and to use circumferential locking keys.

Cases were found in which the dovetailed slots were so wide that packing strips had been inserted to keep the core-plates from shaking. When complaints were made the maker asserted that it was not possible to machine so accurately as to avoid the use of such packings!

It is the practice of some makers to make semi-enclosed winding slots in the core plates by first punching a closed slot and then, when the whole core has been clamped up, to cut through the periphery of the core at the top of each slot by means of a saw. Quite a number of motors have been made in this way, and it was found that the result of the saw-cutting was to spring out the tips of the teeth on each side of each ventilating space, so that the spaces were almost closed in many cases. It was only by taking out the rotor that the fault could be seen. The correct way to make semi-open slots is to punch them out at one operation.

Difficulties were experienced in many cases from the type of distance piece used to form the ventilating spaces in the stator and rotor cores. This was a plain, thin steel strip, placed radially on edge and secured to one of the adjacent core-plates by simple riveting. The necessary pressure used in clamping up the core-plates was too much for many of the distance pieces and, instead of remaining firmly at right angles to the spaces, they bent over and partially collapsed. The area of contact between the edge of the strip and the face of the plate was in most cases found to be too small to take the pressure, and particularly where the core teeth were wide the teeth at the ventilating spaces were badly bent. Distance pieces of

[illegible] the motor maker and does not look into the dictionary to find the proper words.

[illegible]

Minimum radial air-gap in mm.

$$= \frac{\text{square root of rotor diam. in mm.}}{[illegible]} - [illegible]$$

[illegible] manufacturing errors are not accepted.

A serious fault with many 3-phase winding motors is in the sizes of the rotor slip-rings and brushes. Contact areas which are large enough for motors in which the slip- [illegible] insufficient when the brushes and rings are in use the whole time. A current density of not more than 60 amperes per square inch should be the maximum for carbon brushes.

A similar fault is to be found in the motors and generators of some Ward Leonard winders, and in this case the R.M.S. rating is not the controlling factor. The brush area should be based on the maximum current passing on accelerating the winder, which current is frequently twice [illegible]

[illegible] short-circuiting arrangements are generally very defective has already been mentioned. It would appear to be a difficult matter to design them so that a large area of contact can be provided in the space usually available, and so that the sliding collar which carries the contacts can be accurately centered and held free from shake and side movement when the brushes are lifted. A great deal of the difficulty would, however, be removed if [illegible] diameter. The fact that the peripheral speed would be [illegible]

[illegible] temperature rise exceeding 30 degrees C., with the surrounding air at a temperature of 25 C. This corresponds [illegible] altitude of 6,000 feet, with a sur[illegible] if a long life is to be obtained.

[illegible] normal, the lowest supply pressure must be taken for the purpose of the test.

[illegible] motors intended for the Witwatersrand, or [illegible] where the supply pressure has considerable var[illegible] current which is entailed by the lower voltage limit.

The great objection which most makers put forward to a lower temperature limit is that it would increase the cost of the motor, or it would mean the use of a large[illegible] tune, and, unless the customer insists on his re[illegible] being met, the great competition between various makers will probably result in machines being supplied which are [illegible] under-cutting, the representative of a very well-known firm [illegible]

motors kept in stock by that firm, "Output plates are cheap."

Some manufacturers have not yet learned the important lesson, that in order to succeed they must be prepared to supply what the customer wants and in the manner that the customer wants it, and not try to prove to the customer that he does not want what he wants but what the manufacturers make. As a matter of fact few manufacturers make any real attempt to find the requirements of any particular market, and a still smaller number make any real attempt to meet such requirements. Then they express surprise when the market leaves them.

(*b*) *Faults in manufacture.*—For faults in design there may be the slight excuse that the designer is limited in his experience of the particular duty that will be required of the plant which he is designing. For faults in manufacture there can be none. What then can be said of the undermentioned list, the items of which are a few of many that have come under the personal knowledge of the author during the last four years, and all of which occurred in the work of firms of world-wide repute?

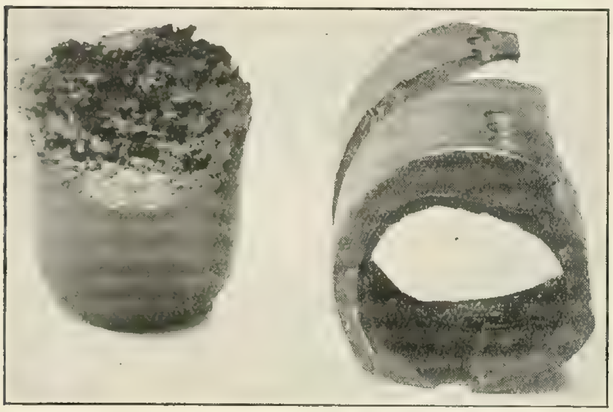


FIG. 12.—Broken Shaft and Broken Brake Pin.

In one case the several sections of a cast-iron bedplate of an electric winder would not fit together, even by persuasion, although the maker seriously stated that they had been perfectly fitted in his shops. Doubtless the higher temperature and relative dryness of the atmosphere on the Rand had something to do with it.

The shaft of a 100 h.p. motor, driving a tube mill, broke off just outside the coupling. The method of manufacture can only be guessed at from the right-hand object in Fig. 12. The shaft had layers just like an onion, and these layers had apparently been wound on spirally and then welded together.

A steel pin, 3 in. diameter, supplied for part of the brake gear of an electric winder, showed one or two surface flaws when inspected on delivery. A slight blow with a hammer broke the pin in halves, with the result shown in the left-hand object in Fig. 12. It proved to be made of cast steel instead of forged steel, with a blowhole covering almost the full diameter. When it is remembered that men's lives would in all probability have been lost when the brakes had been applied a few times, some idea of the seriousness of the case will be obtained.

The instance of the 3-phase winding motor in which the dovetails were adjusted from outside has been mentioned. As no spring washers were supplied an attempt was made to make the nuts more secure by using them, and, for this purpose, the nuts were removed one at a time. On taking off one of the nuts the bolt end came away with it, and on examination it was found that the original bolt was only projecting through the stator frame for a depth of about two threads. A short bolt end had been screwed into the top of the nut to make it appear sound from the outside. There could be no mistake, as the two abutting ends did not in any way match.

Trouble had been experienced with the stator coils of some 3-phase, 2,000-volt winding motors, and the external taping of some of the end loops was removed. It was found that the slots were only three-quarters filled with wires, the rest of the space being empty. To make it appear that everything was all right, pieces of tape had been carefully screwed up and pushed for a short distance into the slots. These pieces were gradually tapered off where they followed the coil out, so that the external wrapping of tape gave a smooth finish right up to the core. Every other motor of the same size and make was then examined and found to be in a similar condition. It cost the maker a considerable sum to make the motors even passably right.

All stator coils for 2,000-volt motors are now required to be either semi- or completely former wound, and to fill the slots completely.

The most costly trouble to either of the mines was the case of the breakdown of the motors of two large Ward Leonard winders, which failed from the same cause within a few hours of each other, and completely shut down a large shaft for four or five days. The winder shown in Fig. 5 is not referred to, as it was not ordered at the time. The spaces between the turns of the main-circuit coils on the auxiliary field poles had been filled up with some kind of pitch, and the whole was taped over. The armatures had open slots without wedges, and the coils were held down by a number of steel-wire bands. These bands broke away on two of the motors, some of the coils came out, and very bad breakdowns resulted.

When the top halves of the field magnet-systems were removed, lumps of hard pitch were noticed on the faces of the auxiliary poles, and these showed heavy scoring marks where they had rubbed on the armature bands. An examination of what was left of the bands showed that the first layer had been rubbed right through in some places. There could be no doubt that the pitch inside the coils had melted and run down, that it had set hard during the night and that when the winders were started up in the morning the wearing of the bands began. A further examination showed the original source of the trouble. The external connections between the auxiliary pole coils had been carefully taped up by the maker before the motors were delivered. They were found to have been made as shown at the top of Fig. 13. The windings consisted of four copper tapes in parallel, and the cross-connections from pole to pole were made up from similar tapes. Each set of four had been bunched together, one set was laid on the other with a copper plate at the top and bottom, and four countersunk-headed screws, $\frac{1}{2}$ in. diameter, were used to draw the parts together by a screwdriver. The surfaces of the tapes had been left dirty, the burrs made by the drilling

[illegible] The remedy was a simple one. [illegible] interlaced as shown at the bottom of Fig. 13. [illegible]

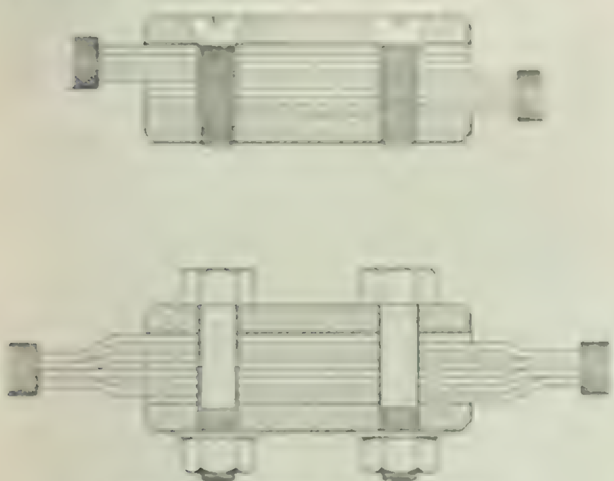


FIG. 13.—Connections on Winding Motor

Many other instances of bad work could be cited but the above examples are characteristic and serve to show what even big firms will sometimes do if they are not carefully watched.

THE USE OF COMPRESSED AIR BY THE MINES

The supply of compressed air from very large compressing stations and its distribution over a wide area are employed for the first time in connection with the mines of the Central Mining-Rand Mines group. To the author's predecessor, Mr. A. M. Robeson, belongs the whole credit for this innovation which has been so successful in practice.

The problem has called into existence steam and electrically-driven turbo-compressors of a size quite beyond previous experience. Three of the steam-driven compressors now in use have a capacity of 2,900 lb. of air per minute at 100 lb. gauge pressure, and require 7,000 kw. each to drive them. The distribution pipes vary in size from 9 in. to 27½ in. diameter, with an approximate total length of 28·4 miles and a capacity of about 310,000 cubic feet. At 100 lb. gauge pressure the pipe system will hold about 90 (short) tons weight of compressed air, and such a large receiver capacity must have a material effect in smoothing out the peaks in the supply curve, thus relieving the air compressing plant.

The range of delivery gauge-pressure of the compressed air to the mines is [illegible] of 90 lb. per square inch. At the higher pressure the pipe system holds about [illegible]

[illegible]

[illegible] no small ones, were at once evident.

[illegible] many thousands.

It is very difficult to keep the joints of underground air pipes tight, [illegible] obtained. [illegible] lent to a hole [illegible] to a Prime Minister's salary."

[illegible] at times when it w[illegible] all air-pipe lines and joints is periodically made, while the [illegible] check.

[illegible]

backwards and forwards under the pressure of the air, the direction of which is controlled by a small automatic valve. Several hundred strokes per minute are obtained at full air pressure, and the drill and piston are automatically rotated at a comparatively slow rate by means of a rifled bar and ratchet. The machine is mounted on a portable carriage, not unlike a small lathe bed, and the rapidity and strength of the blow are varied by regulating the air stop-valve.

In the hammer machine-drill the piston is not connected to the drill, but reciprocates freely within the cylinder. On its forward stroke it strikes a heavy blow on a loose steel block or anvil at the end of the cylinder, to which the drill is secured, and this acts as a hammer at the end of the drill. The drill is kept hard up against the rock all the time.

Piston machine-drills are generally much heavier than hammer machine-drills, and each class has its own special qualities which fit in for certain positions and types of work. They each have a similar property of wasting air unless they are well made and well looked after.

From the character of their work rock machine-drills are subject to very rough usage, but will operate successfully even with the pistons and cylinders badly worn, the only result, and one which does not appeal to the miner, being an abnormal consumption of air for the work done. So long as a machine-drill will continue to drill, the average miner will continue to use it and generally only sends it to the surface for overhauling and repairs when some part or other is either worn out or broken. Under these circumstances, and until means were available for accurately measuring the air, it was not surprising that the air consumption was very heavy.

By developing a system of machine-drill maintenance, originally introduced at Village Main Reef, Ltd., by Mr. W. Calder, the resident engineer, and applying it on all the mines of the group, very substantial savings have been made in the amount of air used by the drills, etc., which, coupled to the savings made by stopping leaks, etc., have had the effect of reducing the air units per equivalent work done from 100 per cent in 1911 to about 63 per cent in 1914.

All new machine-drills, of say 3¼ in. standard bore, are now ordered with cylinders bored 3 in. diameter and with pistons 3½ in. diameter. As the cylinders and pistons wear, the former are bored out in steps of 1/32 inch and the latter are ground down in similar steps. The new drills, with small cylinders, are first fitted with old pistons which have been reduced to the limiting minimum diameter, while the new pistons are first fitted into old cylinders which have been bored out to the limiting maximum diameter. The same procedure is adopted with the valve chests, valves, etc.

Each drill, whether it apparently requires examination or not, is brought to the surface in turn at short periods and taken to the drill shop. It is there thoroughly overhauled, all defective parts are made good, and particular attention is paid to the cylinder, piston, and valve. The cylinder (or valve chest) of any drill in which the piston (or valve) is more than 1/500 in. slack is reamered out to the next standard size, and is fitted with a piston (or valve) which has been ground down to suit.

Thus, as the cylinders and valve chests get larger and the pistons and valves smaller, they are changed about so as to work through the range of sizes, and by this means the parts have a maximum life, and once in about every three months are certain of fitting within 1/500 inch.

Before the drills are again passed for service they are tested at full air pressure with a meter in circuit, and any drill which takes more than a fixed quantity of air per hour is put back for further examination and is not allowed to go into the mine until it is satisfactory.

The drill fitter on each mine works under contract, and has to maintain all the drills up to a certain standard at a stated price per machine-drill shift. The system has been in operation most successfully for over two years, to the advantage both of the drill fitter and the mine.*

Air is used in small quantities for a few winches and pumps, in places where it is not convenient to carry electric cables and where pipes are already in existence, as well as for operating the doors of rock chutes, etc. For a short time each day fairly large quantities are used, after blasting, for blowing out the workings, particularly in dead ends and those parts of the mines where good ventilation is difficult. Much more attention is now being paid to mine ventilation than in the past, and as the systems are made more perfect less compressed air will be required for removing the blasting fumes. It must be remembered that the exhaust of every working machine-drill is discharging fresh air into the mine.

Conclusion.

The author feels that he has not done proper justice to his subject, but to deal with the matter exhaustively would have required a book and not a paper. In conclusion he wishes to place on record his appreciation of the high engineering ability displayed by his predecessor, Mr. A. M. Robeson, in the negotiations which led to the signing of the power contract and the formation of the Rand Mines Power Supply Company, Ltd., and in preparing the scheme for the utilization of electric and air power on the mines, the details of which the author has been privileged to amplify and carry out. Also to express his thanks to all the members of his staff, both present and past, for loyal and unstinted service, and particularly to Mr. E. G. Izod (who has succeeded him as Consulting Electrical and Mechanical Engineer to the Central Mining-Rand Mines Group) and Mr. E. J. Laschinger, M.Sc., whose knowledge of the intricate details of the power contract and the use of compressed air has been of the utmost value.

* For valuable information *re* rock drills, see paper on "Air consumption and maintenance costs of rock drills," by Messrs. E. G. Izod and E. J. Laschinger, *Proceedings of the South African Institute of Engineers*, vol. 12, p. 81, 1913.

Discussion before The Institution, [illegible] April, [illegible]

[illegible] Mr. A. [illegible]: [illegible] allowed for, with [illegible] purchasing power whenever a suitable supply is available. [illegible] been to save the consumer a relatively small amount of capital, perhaps about 4 per cent, although the result was to increase the total investment needed to provide and utilize the supply. As the consumer in this case is under no obligation when selecting its plant to consider the [illegible] supply. The company therefore adopts the best practice, in the present state of the art, to furnish the supply, and the consumer treats the supply in whatever manner it pleases, the demand frequently fluctuating many thousands of kilowatts. I see that the author wishes that the supply were given without any appreciable variation, in spite of any treatment to which his clients may subject the system, but I expect he really knows that such an obligation on the power company would under the circumstances have been one-sided and unfair. Further, I expect that fewer direct winders would have been installed had the author specified the plant; and in my opinion this would have led to even better results, both commercially and tech[illegible] point of view, but the satisfaction of the consumer over the great economy in air consumption effected owing to the genius of the author is not felt to the same extent by the power company who installed plant to give the full supply notified by the Rand Mines, thereby increasing its costs and financial responsibilities. In conclusion I should [illegible]

Mr. J. [illegible]: [illegible] air units is more than the total number of units generated [illegible] factor, which is something like 75 per cent. I [illegible] whether the author thinks 25 per cent of reserve plant is really sufficient when such plant consists entirely [illegible] which are more likely to go wrong than the [illegible] steam engine. With regard to the range [illegible] sure, it seems extraordinary to have a [illegible] inserted in the contract. I have [illegible] like to know if in view of the dangers of flash-overs such winders are entirely reliable without the eddy-current brake mentioned later in the paper. I gather that the [illegible] the kinetic energy [illegible] is reduced. I do not know what Mr. Ha[illegible] that point; perhaps he will not thank me for making the [illegible] it that it is from the user's point of view the paper is written—there is considerable advantage in installing a Ward Leonard winder, even though it may cost a little more in capital outlay. It seems to me that the control [illegible] in every respect for a pressure of 1,500 volts to which it may be subjected, and for constant working. The author speaks about pipe framework not being quite suitable for [illegible] in the paper? One would like to know why overwinding devices receive [illegible] room shown in one of the slides it would appear that overwinding devices would have been useful if the driver forgot to apply the brakes at the right time. With regard to shaft pumping, can the author give us any idea what

Mr. Shepherd

is the limiting head at which the large multi-stage pumps work satisfactorily? It is certainly only a matter of something like 20 to 25 years ago since a centrifugal pump of any design was not considered suitable for even a moderate lift of only 100 feet; and now we have descriptions in this paper of centrifugal pumps with lifts of thousands of feet. Coming to a matter on which most of us have a good deal of experience, that is plant troubles, I notice that the author refers to the old familiar trouble of soft cores due to ventilating vanes, either of insufficient strength or of insufficient thickness. I am rather surprised that nothing has been said about trouble from unsuitable insulation and dust, especially after seeing the dusty situations shown on the lantern slides where some of the motors are installed. May we take it that practically no trouble has been experienced from either of those causes? If, however, that is not so, how was it overcome? The author said that a drive of a very high ratio could not be arranged with only one spur-gear reduction. It is very obvious, I think; the ratio is too high on the gearing shown on the screen. Was worm gear ever tried? Why did the author go to belt driving; was it to get an elastic medium between the source of supply and the work, or was it merely to reduce the high ratio of a single spur gear? Dealing with the defective winding which the author describes as consisting partly of conductors and partly of rolled-up tape inserted inside the insulating tube, we should all like to know whether that work was British or foreign. With reference to the question of the heating of motors with low atmospheric pressure, would the author say whether the rise in temperature varies exactly in the inverse ratio to the air density. One would imagine that it did, but the author's experience would be useful, as indeed are all his remarks when the Institution is so fortunate as to hear him.

Mr. Sparks.

Mr. C. P. SPARKS: It shows the great vitality of this Institution when the first act of a leading member on returning to this country, after having been away for four or five years, is to come before his fellow members and tell them what he has been doing, and to add to their knowledge by giving a detailed description of this important undertaking. With regard to winders, the author adds considerably to my knowledge, and I think to that of a great number of the members, by bringing clearly before us the characteristics of continuous-current and 3-phase winders, especially with regard to control. I gather that the larger winders are all of the Ward Leonard type. If that is the case, it seems that the author has found out exactly what we have found out here, namely, that while 3-phase motors of moderate size can be efficiently controlled, the difficulties of control are greatly increased in the case of the larger sizes. The paper entirely bears out my view, that when we come to these big winders we must use the Ward Leonard system in order to get the best results for both the user and supply company. Up to the present I have only employed the liquid-resistance method of control for alternating-current motors. The motors are of moderate power compared with those mentioned by the author, the biggest being about 1,000 b.h.p. One difficulty of liquid controllers is referred to on page 617, where the author tells us that he has substituted metallic resistances controlled by contactors, and under (c) that "the full speed of the motor is obtained, as, when the last rotor switch closes, the rotor is metallically short-circuited." That is of enormous advantage, because even with more moderate rotor pressures than those he mentions, it is impossible to work with a less slip with liquid resistances than about 10 per cent, and I think the paper will have a great effect upon the future method of control of such motors, that is to say we shall adopt his method of using metallic resistances and the contactor system. Then I should like to ask a question with reference to the pumping. The author states that the development of high-lift centrifugal pumps was only taken up on the Rand in 1912, the pumping plant electrically driven being of 30,000 horse-power. I should like to know approximately what percentage of the total pump power the high-lift centrifugal represents, as it appears unlikely that the author has converted anything like 30,000 horse-power within the last 2 years. In Europe long before 1912 we were working pumps of 1,000 and 1,100 horse-power against heads of upwards of 2,000 feet. The conditions in coal mining are very different from those in metalliferous mines. For instance, ventilation is on quite a different scale. Ventilation is a very important matter in coal mines, not only because the men require air when working in a high temperature, but also for sweeping away gas. On the Rand they have not to be so particular about ventilation as there is no gas to deal with, but at the same time I think the efficiency of the labour would be improved if more attention were paid to this matter. On page 625 of the paper only a line and a half is devoted to ventilation. With regard to the question of regulation, on page 610 the author refers to the disadvantage which the users have experienced owing to the wide limits of pressure and frequency allowed under the contract for the supply of power. So far as frequency is concerned, in England we have a Board of Trade Regulation of $2\frac{1}{2}$ per cent up and down. That is sufficiently wide that if it were reconsidered I think 1 per cent could be taken as a practical standard. There is no necessity for such wide limits. Then with regard to the pressure regulation, the Board of Trade Regulations for Power Companies require a minimum pressure to be declared with a maximum rise of $12\frac{1}{2}$ per cent. I do not think that the successful results that have been achieved in South Africa could have been obtained if the power company had, except on exceptional occasions, taken advantage of a clause allowing limits of + or — 10 per cent. The author, in referring to frequency, points out the great disability that the users have been under, but no details are given of the difficulties with large pressure variation. If the pressure-variation clause had been taken full advantage of he could not have worked at such a high power factor. If the average power factor is 77 per cent, the pressure must be nearer the standard than is suggested by a pressure variation of 10 per cent up or down. I should like to differ from what the author says on page 618 about "Wake up, England!" I think he should not have made that reference. Under normal conditions the enquiry referred to would have arrived in England in August. England woke up very early in August in regard to matters material to the future of our Empire.

Mr. H[unter]

Mr. P. V. HUNTER: There are only one or two questions that I wish to ask, and I do not think there is anything

[illegible] three instruments on the one set of transformers. The [illegible] to this paper, taken as a whole, very much endorses the [illegible] ment. I hope the paper will bring that fact home to a number of consumers, in particular those who take power [illegible]

Mr. R. T. SMITH: The author deals at commendable [illegible] one reading before that particular meter is said not to register properly, shows the commercial value of accuracy, because 3 per cent on the figure mentioned on page 610, [illegible] cancel out in the mean of the three readings. I should like to ask if the A.E.G. and the General Electric meters were of sufficiently different types for the errors to tend to [illegible] rs due to tempera- [illegible]

[illegible] designed, and the master controller is such a small and [illegible] has ever tried to use iron-tube [illegible] circulating through them. That method [illegible] fully used for laboratory purposes for al[illegible] quantities of energy, with a rubber-tube [illegible] insulate the water column.

Dr. A. H. RAILING: Th[illegible] lesson, that in order to succeed they must be prepared to supply what the customer wants and in the manner that the customer wants it, and not try to prove to the customer [illegible] facturers make." He there speaks in a way which I should [illegible] the past, and had to [illegible] directions. There is first the mental inertia of [illegible] who [illegible] tries to adhere to [illegible] been [illegible]ed. There is, [illegible] cases, a certain, shall I call it, excess [illegible]

Dr Railing. some of the requirements that come home, and one does not quite know whether to meet them or reject them. I can only say that the author will find now he has come home that matters have altered very greatly during the last few years. If requirements are studied as carefully as he has studied them at the Rand; if all specifications are drawn up so much to the point as I know the Rand Mine specifications are drawn up; if he bears in mind that all big organizations now have as their representatives abroad engineers instead of salesmen; and if he also remembers that most British firms to-day are not controlled solely by commercial men, but have engineers in the most important positions on their councils, I am sure the author will come to the conclusion that the spirit to which he refers no longer prevails, and that manufacturers are only too anxious to meet the reasonably expressed requirements of engineers like himself. In conclusion, I should like to refer to a point that Mr. Shepherd mentioned, viz. that the number of units taken by the Rand mines is greater than the total number of units sold in the London area. I understand that the latter number is more than 1,000 million, including the railways and tramways, and I should like the author to state whether the figure for the Rand mines is smaller or greater.

Mr. Hammond. Mr. R. HAMMOND: It has been my lot to regard this subject more from the generating point of view than from that of the consumer. I well remember that day in Johannesburg in 1905 when I read a paper before the Engineering Section of the British Association* on the distribution of electricity on the Rand, when I was bold enough to advocate—it was not my own idea, and it was obvious to every thoughtful engineer that it must eventually take place—the great advantages that would accrue from a central supply of electrical energy for the varied uses of the Rand mines. It was not left to England to start that scheme, though it fell to an Englishman, Mr. Hadley, to take the lion's part in making it the huge success that it has attained. One of the points upon which I laid stress in my British Association paper was the great advantage that would result from the diversity factor, and that is the point that specially appeals to me in connection with this paper. It contains some very remarkable figures in regard to diversity factor, and I should like to draw attention to them. The author says that the total horse-power of the motors is 142,300, and the maximum demand is 47,300 kilowatts. One speaker's remarks seemed to imply that this paper summarized the requirements of the whole of the Rand mines, but as a matter of fact it only deals with the company with which the author is associated. Consider, for instance, the winders; there are 69 winders with a total capacity of 57,000 horse-power. I was confronted in Johannesburg, when I read my paper, with the argument that generating plant would have to be installed of sufficient capacity to cope with the whole of the winders, on the basis of the whole of them being possibly in operation at once. This view I strongly contested. Diversity factor, however, obviously comes to the aid of such a concern as this, as Mr. Rider's figures so abundantly prove.

Mr. Fasola. Mr. J. J. FASOLA: I regret that the author has encountered difficulties in setting before us a comparison of costs between Ward Leonard and 3-phase winders, and that in a practically unique case like this where electrical winding is carried out on such a large scale there do not appear to be available any energy consumption figures or interest, depreciation, and upkeep costs per shaft horse-power on the electrical equipment of the two systems. It is already a strong argument for the electrical conversion of steam winders to refer to what has been done so successfully as described in this paper, but it would be a still more potential argument to be able to refer to practical energy consumption figures, such as, for instance, some statement to the effect that the energy consumptions measured during normal winds per "short" ton raised 1,000 feet vertically range between, say, $1\frac{1}{4}$ units and 2 units, with an average of say $1\frac{1}{2}$ units. By simple multiplication with the price per unit of the local supply authority a sufficiently attractive idea of the cost of electrical winding could be obtained to induce engineers to carry out further investigations by means of diagrams. The author refers on page 613 to R.M.S. rating. There appears to be a considerable diversity of opinion among manufacturers as to whether the equivalent continuous rating of the motors at full speed should be the R.M.S. diagram output taken over the running and stopping periods, or whether more or less large marginal corrections should be made for the reduced ventilation during acceleration, retardation, and stops. It would be interesting to know the Rand practice in this respect. In connection with the improved design of liquid controller mentioned in the paper, it is explained on page 617 that "the electrodes should be at a safe distance apart when the rotor voltage is high and the current low." Judging from any typical torque diagram, especially where self-dumping skips are used, I should imagine that at the moment of starting, with full voltage across the rotor, the rotor current would be a maximum, not low, and that during counter-current retardation on the other hand the current would be usually relatively low and increase slightly as the pressure decreases from double to about full voltage. This seems theoretically to complicate the conditions with a single set of electrodes. It occurs to me that instead of using two tanks and a change-over rotor switch it might be feasible to arrange two sets of differently-spaced straight rods in one tank connected in parallel during starting, and to arrange for the one set of starting electrodes to be simply disconnected from the circuit by means of a double-grip lever during counter-current braking. In comparing the Ward Leonard and 3-phase controls the author does not deal with the great advantage of the Ward Leonard control being dependent upon the position of the lever and independent of the load, and the consequent advantage with this particular system of being able to arrange cams on the depth indicator to limit automatically and mechanically the speed at which the winder can be manipulated near the tip and prevent starting up in the wrong direction without otherwise interfering with the driver's useful command of the winder. Is the Philip's device still considered desirable in this case? I am glad to hear the author's views in respect to low temperature-rises and large air-gaps even at a small sacrifice of power factor. The very serious losses which may accrue from the stoppage of certain motors on gold mines seem in many cases a sufficient reason to warrant preference being given to motors with former-wound stator coils in open slots and rotor bars clipped at

* R. HAMMOND. Electric-power distribution on the Rand. *Report of the British Association for the Advancement of Science*, p. 504, 1905.

[illegible]

with quite a small plant, the cost of electrical energy has been halved by using automatic control gear in place of a hand-operated starter and mechanical unloader. With [illegible] the intake valve [illegible]

[illegible] when first the proposal to generate power for [illegible]

[illegible] with the Victoria Falls Power Company.)

[illegible] ciate. The negotiations and interviews which we had [illegible]

[illegible] If the plant [illegible] and that the plant is never overloaded [illegible] plant in reserve.

[illegible] would be seen upon an ordinary recording chart, *i.e.* fluctuations lasting for a very short time, but low and high [illegible] no real harm. It is the continued supply at [illegible] as the frequency does not vary to anything like the [illegible] and therefore the motors still keep on running [illegible] It is only fair to the power company to state that since the full reserve of plant has been available in the stations the [illegible]

[illegible] the General Electric meters were of sufficiently different types for the errors to cancel out. There is no great [illegible] to the meter readings [illegible]

Mr. Rider. depends upon the kind of fault which we find in the meter. The secondary portable standards of the power company are, generally speaking, found quite reliable enough for testing the meters on site.

Winders.—Mr. Shepherd asks whether alternating-current winders were reliable without the use of the eddy-current brake. Our experience has been that since the control tanks have been altered and made safe from the risks of flashing-over, when reverse or countercurrent is applied for braking, they are perfectly safe. Of course, there is always a little greater risk with an alternating-current winder than with a Ward Leonard, because the former is dependent for its electrical braking upon the power supply from the company, while the latter forms its own self-contained brake. For all practical purposes, however, the alternating-current winder is quite safe, and we have never had any trouble with the working of such a hoist under emergency conditions when it has been an electrical hoist built as such with new mechanical parts. We have had some little trouble with the brakes of old converted steam winders, but that was only to be expected, because in a steam winder steam is generally used for braking and the mechanical brakes are only called upon to hold the drums when they are stationary. In several cases new mechanical brakes have had to be supplied.

Mr. Shepherd asks if the contactor gear shown in Figs. 2 and 3 is quite satisfactory for 2,000 volts on the stator and 1,500 volts on the rotor. I am afraid the illustrations do not make the insulation arrangements very clear, but they are quite satisfactory in working. The pipe framework referred to as being unsuitable is the standard pipe framework made by the General Electric Company of America. I do not like pipe frameworks for switchgear and, as is pointed out in the paper, it had to be replaced on this particular job, and, as a matter of fact, on a number of other switchgears in addition.

Mr. Sparks suggests that large winders should be of the Ward Leonard type. This is the case on the Rand, the largest winders being of 4,000 horse-power continuous rating. There are, however, a number of alternating-current winders of 1,500 horse-power continuous rating, but I quite agree with him that the larger the size the greater are the difficulties of control in alternating-current winders. In referring to the contactor control-arrangements Mr. Sparks finds fault with me in asking England to "wake up" in this connection, and he suggests that the war was the real reason why no proper reply was sent to my letter. I cannot agree with this at all, as a full reply was sent, but the information it contained was entirely useless, and I do not think the person who answered the letter could have taken the trouble properly to read the description of our requirements which I sent to him.

Mr. Rees gives some interesting figures regarding the use of contactor switches, but it does not appear that any of them refer to 3-phase winders or large horse-powers and, as he states that the requirements of the mines can now be dealt with by British firms, it will be for such firms to send me particulars of what they can do, as the actual requirements of the case are set out clearly in my paper.

Mr. Smith refers to a drum type of water controller. I have not seen this particular pattern, but do not think it would be suitable for winders, however well it may answer for the starting of small motors. The inertia of the Mr. Rider. moving parts would appear to be one of its drawbacks, as a control tank for a motor of anything like 1,000 horse-power is a fairly heavy piece of apparatus. With reference to Mr. Smith's suggestion that iron-tube resistances could be used with water circulating through them, this method was considered in connection with the arrangements at the Village Main Reef, but possible complications with reference to the earthing of the rotor prevented its adoption.

Mr. Fasola raises a very important point in connection with the R.M.S. rating of winder motors. Until recently it was the practice on the Rand to take the R.M.S. diagram output over the running and stopping periods, but now the following practice obtains, which in my opinion gives more correct results:—The time during which the winder accelerates is taken as being half such time, and the time at rest as one quarter of the actual time. I have to thank the General Electric Company of America for drawing my attention to this point. I do not follow Mr. Fasola's remarks with reference to the current flowing in the rotor at the moment of starting. Mr. Fasola considers that this current would then be at a maximum, but this could hardly be so, because at that instant there is a maximum resistance across the slip-rings, while, on the other hand, when reverse current is applied for retarding the motor the resistance would be the same as at starting up, but the rotor pressure would be doubled.

Mr. Fasola considers that the Ward Leonard winder has an advantage in that cams can be arranged on the depth indicator to limit automatically the speed at which the winder can be manipulated near the tipping point. In both Ward Leonard and 3-phase winders similar devices can be used, and in my standard specification they are called for to perform the following duties, namely:—

In a Ward Leonard winder:—

(*a*) To prevent the driver from accelerating the winder in either direction beyond a pre-determined rate.

(*b*) To bring the operating lever gradually back to the neutral position, sufficiently early to prevent an overwind, in the event of forgetfulness on the part of the driver.

(*c*) To allow the driver to operate the winder slowly in either direction, even after the lever has been automatically brought back as in (*b*). This is to be done through the medium of a spring or weight against which the driver has to exert an additional force.

In a 3-phase winder:—

(*a*) To bring the operating lever gradually back to a position where the maximum working resistance has been inserted in the rotor circuit, but without opening the stator switches, sufficiently early to prevent an overwind, in the event of forgetfulness on the part of the driver.

(*b*) To allow the driver to operate the winder slowly in either direction, even after the lever has been automatically brought back as in (*a*). This is to be done through the medium of a spring or weight against which the driver has to exert an additional force.

[illegible]

head at which large [illegible]

[illegible] future.

Mr. Sparks asks as to the horse-power of the centri- [illegible] pumps for mine pumping instead of ram pumps.

[illegible] the difficulty of keeping such gear in proper mesh.

Mr. Hunter quotes me as stating that "the mechanical [illegible] be somewhat inefficient and crude methods are seldom successful." I cannot find any such statement in my paper, and must assume that he is referring to the [illegible] "Although the existing form of stamp mill is such a crude device and has apparently so many engineering defects it has survived and will continue because of its extreme [illegible]"

With reference to Mr. Hunter's suggestion that in the single-arm cam mentioned in the paper the difficulty could have been got over by altering the profile of the cam, I can assure him that the profile was altered, and [illegible] on the Rand tries to do, as there have been [illegible] be satisfactorily altered to any extent worth the trouble.

[illegible]

[illegible] the Rand. It does not necessarily call for a large [illegible] mine ventilation.

[illegible] of oil switch now in use in the switch house on [illegible] as without it such switches would [illegible]

[illegible] connected with insulation and dust, but [illegible] troubles have been comparatively rare. This may be [illegible] exceedingly dry. If it had not been for this there is no doubt that very many more coil breakdowns would have taken place. Dust has not had the effect of causing [illegible] whole motor to pieces, core stampings and [illegible]. This is an impracticable thing, and is one of the reasons why such an apparently low working temperature is called for when the motors are new. The temperature tests which are taken in a maker's works are always taken with [illegible] ing out the ventilating passages, the resultant working [illegible]

[illegible] were mentioned were with British or foreign work. I [illegible]

Mr. Rider. with the increased heating of motors at the high altitude of the Rand whether the heating varies exactly in the inverse ratio to the air density. Within the ordinary barometer limits the temperature of the motor increases about 1 per cent for every 10 mm. fall in the barometer.

Mr. R I have to thank the members very much for the kind reception which they have given to my paper, and it will not have been written in vain if British manufacturers will only take to heart the experiences which I have endeavoured to put before them.

METHODS OF TESTING THE SCHERBIUS COMPENSATOR.*

By ABDEL AZIZ AHMED.

(*Paper received* 19 *February*, 1915.)

The object of the following tests is to determine the electromotive force injected by the compensator corresponding to any load current. A knowledge of the characteristic thus obtained will enable the magnetic state of the armature to be determined. It also provides a direct application, in a simple graphical treatment to be dealt with later, for the construction of the circle diagram for a non-synchronous motor fitted with a Scherbius or similar phase advancer.

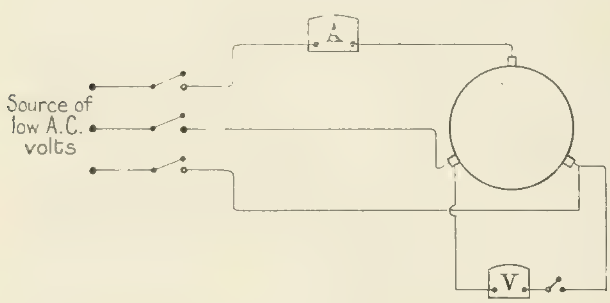


FIG. 1.

The most obvious method of carrying out the test would involve the use of alternating currents. The electromotive force generated by the compensator depends, among other factors, on the relative motion between its armature and the rotating field produced by the secondary current in the armature itself. As far as its magnitude is concerned it is immaterial whether the field is rotating, the armature is revolving, or the two motions take place simultaneously, provided that the current and the relative speed are the same. The sense of the motion, however, influences the phase relation between the current and the generated electromotive force.

If a 3-phase current of a given frequency be led into the compensator while it is at standstill the armature will act as a choking coil (Fig. 1). By varying the supply current and observing the corresponding electromotive force we obtain a curve following the magnetization curve of the armature for the particular frequency chosen. If the frequency of the supply current be so adjusted as to be equivalent to the synchronous speed of the compensator when under working conditions, the corresponding curve will give the required characteristic (Fig. 2).

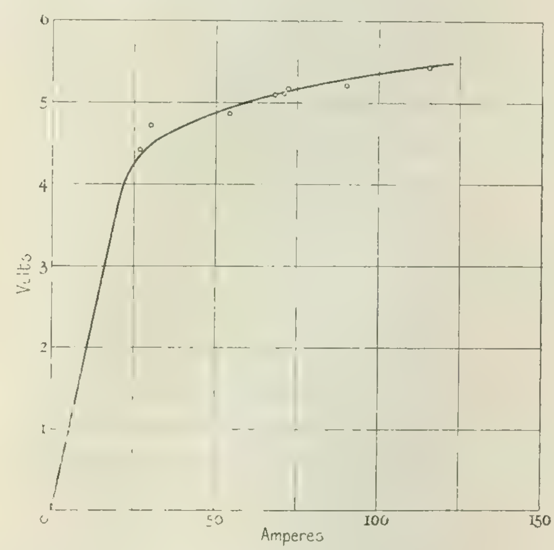


FIG. 2.—Testing Compensator with Alternating Current.
Supply Frequency 34; Speed 1,000 r.p.m. approximately.

If, however, in another test* the current be kept constant whilst the compensator is driven at a constant speed, then by varying the frequency of the supply current, and thereby varying the relative speed between the revolving armature and the rotating field, we obtain the curves shown in Fig. 3.

Starting with a frequency higher than that at which the

* The tests here described were made on a Scherbius 3-phase induction motor built by Messrs. Brown, Boveri & Co. The motor is of 25 horse-power, 450 volts, and 50 frequency, having a synchronous speed of 1,000 revs. per minute. The rotor is the primary, and the advancer is fixed at one end of the rotor shaft. The advancer itself consists of a 4-pole continuous-current armature. The conductors are housed in holes below the external diameter of the stampings. The brushes on the commutator are connected to the three terminals of the stator. The exciting flux is produced in the armature itself by the secondary current.

* Since this paper was written, an article has appeared in the *Electrician* (vol. 74, p. 783, 1915) by Dr. T. F. Wall describing a test similar to this one. The curve shown therein refers to star values of the potential difference, whereas the curves given herewith (Fig. 3) represent line values.

[illegible]

[illegible]

[illegible] in the armature. Hence it follows that

[illegible]

Fig. 4.

[illegible]

[illegible] must contain a component in phase with the current to account for hysteretic and eddy-current losses. Secondly, [illegible]

It is with the [illegible]

large currents that the following test involving the use of continuous current has been devised.

New Method of Testing the Compensator.

The test consists of circulating continuous current between two or more brushes in a manner to be discussed hereafter, and taking readings of the current and the corresponding line voltage while the compensator is rotating. The results obtained from the following mathematical treatment enable us to convert continuous-current readings into their equivalents for alternating current, and thus to obtain the required characteristic connecting effective values of the compensator current with effective values of the generated electromotive force.

It is evident that the crest value of the alternating current in a 3-phase system can be calculated if we know the instantaneous values of the current in any two phases. Imagine that corresponding to a certain instant it is a permanent condition. The current will thus remain unidirectional or continuous current. The author will show later that if a and b are the values of the current in any two phases, then the corresponding crest value of the current is given by

$$I_{max.} = \frac{2}{\sqrt{3}} \sqrt{a^2 + a\,b + b^2}$$

Hence the effective value is given by $I = I_{max.}/\sqrt{2}$.

It is therefore possible by the suitable selection of any two values of the continuous current for a and b to represent any given crest value.

A similar expression for the effective electromotive force is obtainable in terms of the line potential difference in any two phases. Since the armature is excited by a 3-phase current the voltage induced depends on the crest value of the current $I_{max.}$. We can only measure line volts between the brushes; it is more convenient to introduce star voltage, the crest value of which the author proposes to call U (radial or star voltage). This is a function of the line current, depending on the magnetization curve of the armature.

The author will show later that

$$U = \frac{2}{3} \sqrt{V_{AB}^2 - V_{AB} V_{CB} + V_{CB}^2}$$

where V represents the potential difference and the suffix refers to the points between which the readings are taken. It is obvious that the effective line electromotive force $= U\sqrt{3}/\sqrt{2}$.

Since the resultant rotating field is constant for the same crest value of the current, it follows that there is a certain value of U corresponding to the crest value of any current, and hence to a certain effective electromotive force.

Calculation of the Effective Electromotive Force generated by the Compensator.

Analytical study of the general problem.—Consider a 3-phase 2-pole armature. Let currents of any value be led into the armature at A and B (Fig. 5), and let their sum total be taken out at C. This represents a typical example of a 3-phase current at any instant.

It can be shown that the resultant flux set up in the armature by such currents, assumed to be sine functions of the time, is constant in magnitude and variable in direction, the latter depending on the relative instantaneous values of the current in the various phases. As the armature rotates an electromotive force will be induced in it in quadrature with the flux and leading on it in the space diagram. Let the star electromotive force O E make an angle ϕ with the diameter through A. Owing to hysteresis and eddy currents the resultant flux will be dragged in the direction of rotation, and the vector electromotive force will move round to correspond therewith. Let θ be the angle swept out by the vector electromotive force due to the above losses, and let O E′ be the new position of O E.

The angle A O E′ is clearly $(\phi - \theta)$; call it ψ.

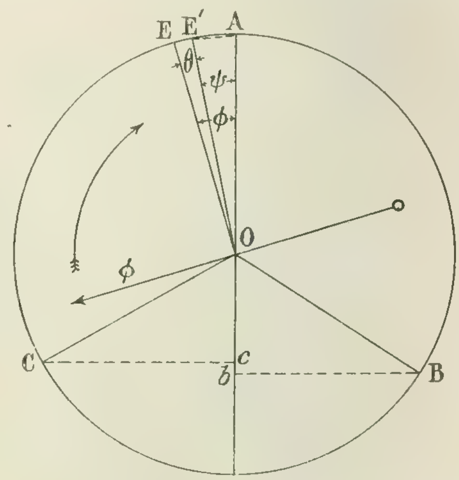


Fig. 5.

The components of O E′ at the brushes A B C are as follows (Fig. 5)

$$O\,a = U \cos\psi \quad \ldots \quad (1)$$

$$O\,c = U \cos\left(\frac{2}{3}\pi - \psi\right)$$

$$= -U \cos\left(\frac{\pi}{3} + \psi\right) \quad \ldots \quad (2)$$

$$O\,b = U \cos\left(\frac{4}{3}\pi - \psi\right)$$

$$= -U \cos\left(\psi - \frac{\pi}{3}\right) \quad \ldots \quad (3)$$

Let V_A, V_B, and V_C represent the potentials of A, B, and C respectively. Let V_{AB} represent the potential difference between A and B. The sequence of the letters in the notation V_{AB} implies that A is of a higher potential than B. Similarly for V_{BC} and V_{AC} then we have

$$V_{AB} = O\,a - O\,b = U\cos\psi + U\cos(\psi - \pi/3) \quad \ldots \quad (4)$$

$$V_{AC} = O\,a - O\,c = U\cos\psi + U\cos(\psi + \pi/3) \quad \ldots \quad (5)$$

$$V_{CB} = O\,c - O\,b = U\cos(\psi - \pi/3) - U\cos(\psi + \pi/3) \quad . \quad (6)$$

We have an identity of three equations; U and ψ being the unknown which can be determined from any two equations. Taking (4) and (5) we have

[illegible]

whence [illegible]

[illegible]

$$\therefore \sin\psi = \frac{\sqrt{3}\,(V_{\ldots} - V_{\ldots})}{\sqrt{(V_{\ldots} + V_{\ldots})^2 + 3(V_{\ldots} - V_{\ldots})^2}}$$

and $$\cos\psi = \frac{V_{\ldots} + V_{\ldots}}{\sqrt{(V_{\ldots} + V_{\ldots})^2 + 3(V_{\ldots} - V_{\ldots})^2}}$$

[illegible]

[illegible]

Hence [illegible]

$\therefore \tan\omega t =$ [illegible]

and $\cos\omega t =$ [illegible]

[illegible]

Substituting in (12) we have

$$a = \frac{I_{max.}\sqrt{3}\,a}{\sqrt{4\,b^2 + 4\,a\,b + 4\,a^2}}$$

Hence $$I_{max.} = \frac{2}{\sqrt{3}}\sqrt{a^2 + a\,b + b^2} \quad . \quad . \quad . \quad . \quad . \quad (14)$$

and therefore the effective current

$$I = \sqrt{\frac{2}{3}\,(a^2 + a\,b + b^2)} \quad . \quad . \quad . \quad . \quad . \quad (15)$$

must therefore be corrected so as to represent generated electromotive force only. The armature pressure-drop can be calculated from its resistance and the current flowing in the phases between which the readings are taken. The evaluation of this current for the general case treated above cannot be put in a simple expression. It becomes, however, much simplified if the test is made for one of the following particular cases.

(1) The case corresponding to $\omega\,t = 11\,\pi/6$ (Fig. 6) when $a = -b$ and the current in line C will then be zero, *i.e.* we have to circulate current between A and B only.

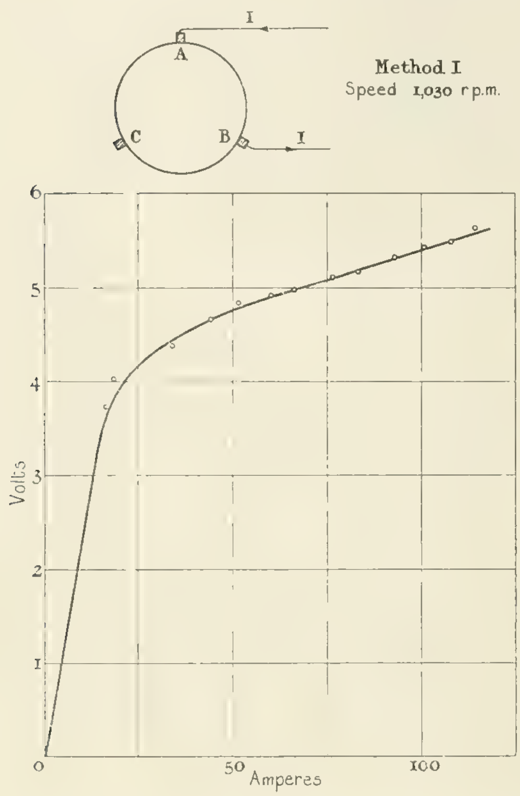


FIG. 7.

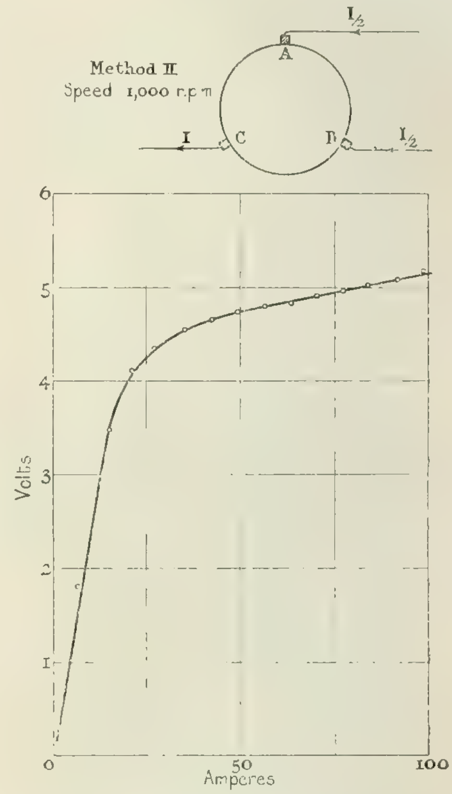


FIG. 8.

Characteristic Curves of Compensator Calculated for Alternating-current Values from Continuous-current Tests.

We must bear in mind that this formula is established on the assumption that a and b are both positive; in other words, that they are flowing in the same direction. If, however, a and b are flowing in opposite directions, then

$$I = \sqrt{\frac{2}{3}\,(a^2 - a\,b + b^2)}$$

PRACTICAL TEST.

In the above treatment the potential differences V_{AB}, V_{BC}, and V_{CA} taken at the segments under the brushes are assumed to represent the generated electromotive forces only. The actual voltmeter reading, however, measures the impressed voltage, which is the resultant of the generated electromotive force and the armature pressure-drop. Since we are dealing now with continuous current it will be equal to their algebraic sum. The observed readings

(2) The case corresponding to $\omega\,t = \pi/3$ (Fig. 6), whence $a = b$, *i.e.* the continuous current is split into two equal parts by means of a rheostat placed in each branch.

The advantage of Method I in addition to its simplicity is that we require a current $\sqrt{3/2}$ times that used in Method II in order to produce the same flux. This is evident from Equation (15) by putting $a = -b$ for case (1) and $a = b$ for case (2).

Both methods have been employed in order to see how far they agree, as they should do according to the above theory. The results obtained are shown in Figs. 7 and 8.

There may be a slight discrepancy between the characteristics, which may be explained to be due to the fact that the flux set up in the armature by alternating current is constant only on the assumption that it is a simple sine wave. The actual wave, however, is only approximately so, maximum flux occurring at the time when the current

in any of the phases is zero. It is a maximum at the time when the current in [illegible] becomes a maximum. The deviation from the theoretical condition is due to the configuration of the winding. It is, however, very small. [illegible]

[illegible]

[illegible] — The [illegible] Fig. [illegible]

Fig. 8.

The [illegible] of Fig. [illegible] are obtained from Fig. [illegible] by substituting in Equation [illegible] the [illegible] corresponding to any given current [illegible]

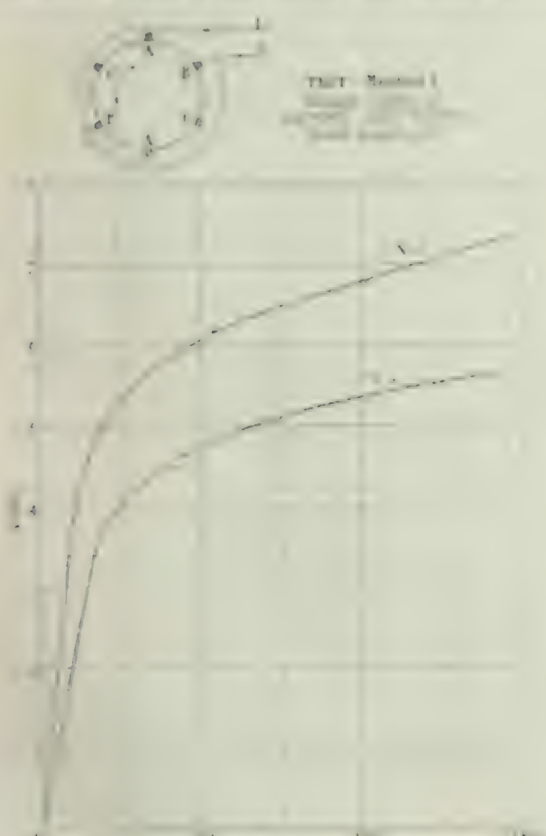


Fig. 9.

[illegible] The [illegible] are obtained by substituting the [illegible] current in Equation [illegible] using the proper sign for the [illegible]

It is observed that C is at a higher [illegible] than either A or B. [illegible] from Fig. 9 [illegible]

[illegible] Hence from A to C [illegible] voltage drop [illegible] added to [illegible] This [illegible]

Fig. 10.

In the case of an accumulator. During the process of charging, a voltmeter connected to the accumulator terminals will read [illegible] than the [illegible]

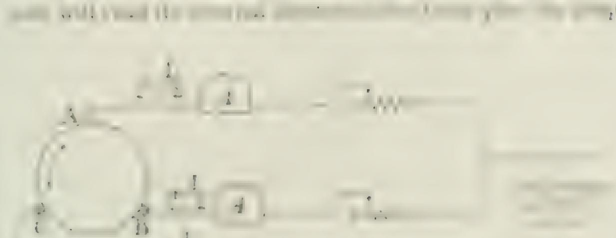


Fig. 11.

[illegible] internal resistance [illegible] the voltmeter [illegible] drop.

[illegible] Fig. 11. The [illegible] are made [illegible] those of Method I.

Graphical Theory of Phase Advancing.

In an induction motor the slip is usually small so that the inductance due to the slip becomes negligible. The slip electromotive force may therefore be drawn in phase with the secondary current. The function of any phase-advancing device constructed on Leblanc's principle is to inject into the secondary an electromotive force leading on the secondary current by 90° and thereby causing the slip electromotive force to lead on the secondary current. This has the effect of improving the power factor of the motor or even making it take a leading current as desired.

Consider the vector diagram of the motor taking the electromotive force injected by the compensator into account. For simplicity assume the transformation ratio to be unity.

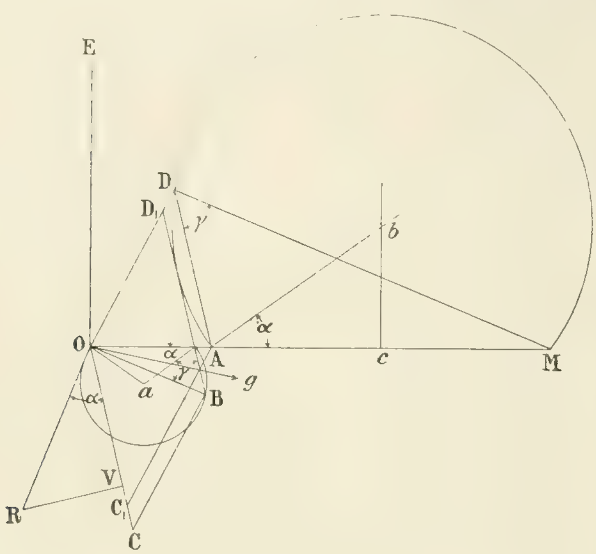


Fig. 13.

Let in Kapp's diagram (Fig. 13) O D represent to a certain scale the primary ampere-turns and to another scale the flux which these ampere-turns would produce if acting alone. Let O C represent the same quantities for the secondary. Let O D_1 be that part of the primary flux translated to the secondary, and O C_1 that part of the secondary flux linking the primary.

O D and O C_1 combined give the resultant flux linking the primary, say O A.

O C and O D_1 combined produce the resultant flux in the secondary, say O B.

O D_1 and O C_1 combined give the air-gap flux O g.

It is obvious that O A is at right angles to the primary voltage O E to which it is directly due. The slip electromotive force being due to the rate of cutting the secondary flux must therefore be drawn at right angles to O B. Let the slip electromotive force be O R, which will be the resultant of the resistance pressure-drop in the secondary circuit.* Let this be O V and let the electromotive force injected by the compensator be V R. O V will be in phase with the secondary current O C and V R will be leading by 90° on O D. Let α be the angle of lead between the slip electromotive force and the secondary current. Since D_1 B is parallel to O C, and O B is perpendicular to O R, then acute angle D_1 B O $= \gamma = \pi/2 - \alpha$. B may be considered to lie on a circle the centre of which a can be found as follows :—

The angle at the centre of the circle L a O $= 2\gamma = 2(\pi/2 - \alpha) = \pi - 2\alpha$. Hence each of the base angles of the isosceles triangle L a O is equal to α. The same argument applies to the point D. The centre of the circle through D can be found by drawing a line b A making with A M an angle α. The point of intersection of A b and $c\,b$, the perpendicular bisector of A M, is the required centre.

Now A M is the ideal short-circuit current of the motor. It may be regarded as having identical values whether the motor is working with or without the compensator. A M is therefore constant and independent of α. Thus corresponding to various values of the angle α we get a series of circles the centres of which lie in $c\,b$. There is, however, only one working point such as D lying on each circle. The curve passing through all these points is the locus of the primary-current vector.

All this is well known ; it has been pointed out by Professor G. Kapp * and applied by him in the case of his vibrator. In the case of the Scherbius compensator, however, the construction of the load curve is particularly simple.

Let α be the secondary phase angle as defined above, then we have

$$\tan \alpha = \frac{\mathrm{R\,V}}{\mathrm{O\,V}} = \frac{V_1}{\delta}$$

where V_1 = injected electromotive force corresponding to any secondary current and δ represents the brush drop plus the ohmic drop in the secondary and in the compensator.

Let σ_0 be the natural slip of the motor and σ be the slip of the motor working with an advancer corresponding to angle α.

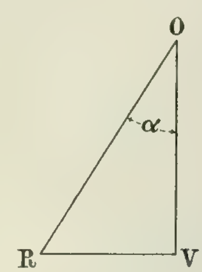


Fig. 14.

It is obvious from Fig. 14 that the electromotive force injected by the compensator has a component along and opposing the slip electromotive force, and this has the effect of increasing the slip of the motor thus †

$$\frac{\sigma_0}{\sigma} = \cos \alpha$$

or

$$\sigma = \frac{\sigma_0}{\cos \alpha}$$

* This also includes the armature pressure-drop as well as the brush pressure-drop in the compensator.

* *Electrician*, vol. 69, pp. 222 and 272, 1912 ; and *Elektrotechnische Zeitschrift*, vol. 34, p. 931, 1913.

† *Journal I.E.E.*, vol. 42, p. 599, 1909 ; and vol. 50, p. 332, 1913.

[illegible]

[illegible]

[illegible] the ordinate of the characteristic curve previously dealt [illegible]

[illegible]

[illegible]

brush drop with the current, and it was found to agree with the formula *

$$d = \Delta^{0\cdot15}$$

where d represents the brush pressure-drop in volts and Δ the current density in amperes per square centimetre.

The main object of making these tests on the brush pressure-drop was not to establish a general formula, but rather to determine the actual values of the drop in the particular machine under consideration, and in order to be able to illustrate the theory in question with considerable accuracy. While the formula does not claim to be generally applicable, the author believes that it can be used to some extent in similar tests, for it is the result of several careful experiments.

Graphical Construction of the Circle Diagram for the Scherbius Induction Motor.

Consider Formula (16)

$$\tan \alpha = \frac{V_s}{\delta}(1 - \sigma) \quad . \quad . \quad . \quad . \quad . \quad . \quad (16)$$

Since the slip is a very small percentage of the synchronous speed we can replace $(1 - \sigma)$ by $(1 - \sigma_0)$ in (16)

$$\therefore \tan \alpha = \frac{V_0}{\delta}(1 - \sigma_0)$$

Let O P B be the characteristic curve of the compensator when revolving at the speed of synchronism (Fig. 15). Let the ohmic and brush pressure-drops and their sum total be those shown in Fig. 15.

* A formula which takes the pressure into account gives the brush pressure-drop $E = \frac{i^{0\cdot28}}{1 + 0\cdot22\sqrt{p}}$ (see *Journal I.E.E.*, vol. 38, p. 153, 1907). The comparatively high drop is due to the necessity of using hard brushes to avoid sparking.

For a certain secondary current O A we have $\frac{V_0}{\delta} = \frac{AB}{AC}$.

The slip corresponding to O A can be found from the circle diagram for the motor working without the compensator (Fig. 16). O A has to be reduced to the primary circuit, which can be done graphically from the transformation ratio. Hence the speed of the compensator $(1 - \sigma_0)$ can be scaled off. Let this be represented by O E (Fig. 15).

$$\text{Hence } \tan \alpha = \frac{V_0}{\delta}(1 - \sigma_0) = \frac{AB}{AC} \cdot OE$$

$$= AB \cdot \frac{OD}{AC} = AB \cdot \frac{OF}{AB} = OF = \frac{OG}{GH}$$

where G H represents 100 per cent to the same scale as O E.

$$\frac{OG}{GH} = \cot GOH$$

Hence $\alpha = (90^\circ - GOH) =$ angle H O E.

The circle diagram in question is shown in Fig. 16. The curve is plotted point by point for various values of the secondary current. The operation is as follows :—

Draw from A (Fig. 16) a ray making with A M an angle equal to α (previously determined in Fig. 15). The intersection of this ray with the central line of the ordinary circle diagram gives the point b. With b as centre strike an arc through A. With A as centre and radius equal to the secondary current to which α refers, reduced to the primary circuit, strike an arc to cut the former arc in D. Then D will be the required point on the input curve. The process is repeated for various secondary currents. The curve joining all points similar to D will give the required circle diagram.

DISCUSSION ON

"ELECTRICITY APPLIED TO MINES."

[illegible]

... "give and take" arrangement between a municipality on the one hand, and a company on the other, has been made in connection with electricity supply in [illegible] ... whenever a breakdown occurred there [illegible] ... in the extreme north and the other in the extreme south of the area. The trouble in con- [illegible]

[illegible] ... would be the case with [illegible]

[illegible] ... This is raised from two [illegible]

Mr. Scott. given for the first mixed-pressure turbines quoted for in this country. To the best of my knowledge, these were the machines which I installed at the Oakdale Colliery for the Tredegar Iron and Coal Company in 1907. These machines were specified to be capable of working with both high-pressure and low-pressure steam in any proportion and to develop at least 75 per cent of their full rated capacity with low-pressure steam only. It is interesting at this date to note the various ideas put forward by the turbine manufacturers to meet these requirements. The following table gives the guaranteed steam consumptions offered, and the proposals are briefly outlined underneath. The speed in each case was 1,500 r.p.m.

Make of Turbine	Load in kw.	Steam Consumption: H.P. Steam, 200 lb. per sq. in. Superheated 200 deg. F. Vacuum 27½ in.	Steam Consumption: L.P. Steam, 17 lb. per sq. in. (abs.), Vacuum 27½ in.	Price for Turbo-generator only
		lb. per kw.-hour.	lb. per kw.-hour.	
A	1,250	16·7	—	£7,000
	1,000	16·6	41	
	750	18·2	40	
	500	21·0	50·2	
B	1,250	17·1	—	£5,350
	1,000	17·4	38·5	
	750	18·2	42·5	
	500	19·2	49	
C	1,250	16	38·5	£5,300
	1,000	16·6	42·5	
	750	17·4	—	
	500	18·1	55·0	

Type A.—One H.P. and two L.P. sections. One of the latter to be cut out and worked in vacua when the machine is operating on H.P. steam. This machine required three governor valves.

Type B.—Single-casing turbine, H.P. end turning in L.P. steam when using exhaust steam only. H.P. and L.P. valves operated jointly from one lever.

Type C.—Double-casing turbine, H.P. end arranged to work in vacua when using exhaust steam only. Change-over to H.P. or L.P. steam to be made by hand-operated valves. (This turbine was obviously not a true mixed-pressure machine.)

Several other offers were received, but the above are representative of the ideas put forward. It should be noted that only two offers were received for single-casing machines, *i.e.* such as we now term mixed-pressure turbines. The author mentions on page 391 the advantage that would be gained if power companies such as the South Wales Power Company, and companies like the Powell Duffryn Company, could be linked up. I also recognized that point some considerable time ago, in fact in the very early days of power supply in South Wales. Unfortunately, most of the private undertakings have adopted a frequency of 50 periods whilst the power company adopted 25 periods. This of course introduces very considerable complications in linking up the two schemes, as it can only be done by frequency converters. To give an instance. I had to carry out the linking-up of the old Tredegar system, which operates at 40 periods, with the new colliery at Oakdale where the supply is at 50 periods. We adopted frequency converters. These consist of an induction motor on one side and a synchronous generator on the other, these machines floating on the lines between the two systems. We find that in normal working the frequency converter will quite easily "float" its full capacity either way, provided of course that we can provide the wattless component for the induction machine working as a generator. This has proved so successful that I have a scheme in hand, which may mature, for coupling an undertaking to the South Wales Power Company in the same manner. The experience that we have gained with these converters is quite sufficient to show us that the scheme is sound. The slip in the induction machine can be adjusted so that the power passed between the two systems does not exceed the capacity of the converter, and this of course is the advantage that it possesses over double synchronous machines. There is one point which the author emphasizes, but which I hope will not become compulsory. He insists that the neutral point should be earthed. For the transmission lines such as he has had to deal with I think there is every advantage to be gained as regards the high-tension side by earthing the neutral, but on the low-tension side for mining work I am doubtful whether it is advisable. I have had considerable experience of mining work and also with earthed and unearthed neutrals, and I find that we have had less trouble in maintaining the plant and running it with unearthed than with earthed neutrals. When the Merz-Price and other types of leakage devices came forward, it did appear that earthing the neutral would be necessary in order to enable us to use these leakage devices. I looked into the matter, however, to see if we could not get something that would answer the same purpose for insulated-neutral systems, with the result that we are now using a somewhat similar type of gear (it is made by Messrs. Reyrolle), on our insulated-neutral system. It operates in the event of a leakage occurring on opposite phases on two different feeders. For instance, take two feeders A and B, with phases 1, 2, and 3; if phase 1 went to earth on feeder A, and phase 2 or 3 on feeder B, these leakage devices would operate. We have found them very satisfactory. The condition which is most dangerous in a mine with an unearthed-neutral system is the breakdown of one feeder, which might cause another feeder to fail at some distant point in the mine. But as this leakage gear operates with practically the same amount of leakage current as in the case of an earthed-neutral system, it protects us against this risk. We also use leakage detectors, and I find these give sufficiently early warning of defective apparatus, so that we very rarely get an actual breakdown, and the defective apparatus is taken out of service before serious damage takes place. At least that is my experience. The author mentioned in connection with the exhaust-steam plant at Bargoed a new type of exhaust-steam storage apparatus. I should be glad if he could give us the approximate period for which this apparatus would supply the turbine with exhaust steam. The usual Rateau type of heat accumulator would regenerate steam for anything between 60 and 90 seconds. From the size of the apparatus at Bargoed it would appear capable of tiding over about 30 seconds with full load on the turbine. An important point mentioned by the author in connection with this apparatus is the reduction in back pressure on the winders. This is especially so in cases

[illegible] adopted a [illegible]

[illegible] The author sums up the advantage of electric safety lamps [illegible] actual practice that after the adoption of electric safety lamps in a colliery there are fewer accidents caused by falls, the explanation of this being that the collier is able to make a better examination of the roofs and sides. There are numerous other minor advantages, but I think those just mentioned are the most important. As regards

[illegible] badly corroded pots. [illegible] being added to the [illegible] notably [illegible] who have, after a certain amount of instruction, [illegible] themselves to maintain electric lamps in an ef[illegible] electric lamps.

[illegible]

YORKSHIRE LOCAL SECTION, [illegible] FEBRUARY, [illegible]

Mr. W. M. SELVEY: On reading this paper I was struck with the wide range it covers, and the size of the installation it describes. It is much larger than many of our prosperous municipal electricity-supply schemes and it has this difference, that it covers not only the field of the [illegible] turbo-alternators running in parallel, I wish to enquire which were first installed and on which was the onus thrown of running in parallel with the other? I should like also to have any particulars that the author may care to give as to the efficiency of the 5,000 kw. turbo-alternator, as very high efficiencies have been claimed for examples [illegible]

[illegible] from the internal evidence that the steam consumption is better than 13·5 lb. per kilowatt, and in this connection a generous surface has been supplied in the [illegible] If I may take it that the air pump referred to is of the [illegible] exceedingly good results. The author's remarks as to the gas-holder type of steam storage are very instructive. The name mentioned in this connection is, [illegible]

Mr. Selvey. interested in both these types of plant. I should like to ask if the test figures given refer to coke-oven gas and to the reduced loads at which the machines settled down, or whether they were the original test figures, say on producer gas. If they refer to coke-oven gas, such results for a low-compression engine are almost unique. They are better than are usually guaranteed for a large modern gas engine, although I have recently tested a much smaller engine of about 600 horse-power which gives results of the same order. On the direct comparison of steam and gas (at the foot of the first column of page 396), I am inclined to think that these figures are in the same category as the results from a certain combined scheme in Lancashire. I have worked out roughly what could be got with a modern 5,000 kw. set under the following conditions :—

Temperature at nozzles, 642° F. (260 deg. F. superheat).
Actual pressure (gauge) at nozzles, 185 lb. per sq. in.
Vacuum, $1\frac{1}{2}$ in. mercury (absolute).
Turbine efficiency, 75 per cent.
Alternator efficiency, 96 per cent.
Auxiliaries of full-load output, 5 per cent.
Boiler efficiency, 84 per cent.
Margin for 75 per cent load factor from test conditions, 7 per cent.
Heat consumption, 20·3 B.Th.U. per watt-hour,

which is a figure not difficult to justify and does not represent the limit of steam practice. One of the most important parts of this paper is that relating to the author's work on earth-plates. This suggests many points. In connection with all metallic envelopes of high-tension gear now normally described as earthed, whether armoured cable, lead-covered cable, ironclad gear, or the like, if connected to and depending on such earth-plates as are described they would, in the event of a bad fault to earth which is not cleared promptly, give rise to a voltage on these parts sufficient to be dangerous to life. I should like to ask the author if he considers that to be a justifiable conclusion. If so, then it is not advisable to leave iron-clad switchgear entirely accessible. It seems fairly well agreed that earth conduction is electrolytic, and it seems to me therefore that what is wanted is not so much a larger earth-plate as what might be termed an electrolytic trench. By this I mean to bed the earth-plate with its coke packing in a trench of rammed soil (not clay), which has been watered with salt solution or some other cheap electrolyte. I have read with great interest the new matter relating to bell experiments, having been much interested in the past in Professor Thornton's work on this subject. I am still looking for a satisfactory definition of the word "spark." It does not seem to me that the question of volts or amperes alone will settle what kind of spark will cause gas to ignite. The condition and nature of the sparking points must also come into the question. Can some method be devised of measuring the result itself, that is the properties of the spark actually produced? It would seem that some of the difficulties experienced may be overcome by having the "make and break" of the bell in an entirely gas-tight box, and using it purely as an electrical device to produce an alternating or intermittent current which can be utilized to set in vibration a pendulum type of striker.

Mr. Storr. Mr. J. E. Storr: I am sure that, as electrical engineers in a large coal centre, we are very gratified by the remarks with which the author prefaced his paper, in that we may expect full justification of our claims for safety and satisfactory service by the extended adoption of electricity for colliery purposes, and which the South Wales colliery proprietors are satisfied they are getting from the electrical portion of their collieries. There are a few comments which I should like to make in respect of the distribution work. First, with regard to the 3,000-volt distribution work, the distance between the centres of the conductors is very large (see page 396), viz. 3 feet 6 inches vertical distance as against only 15 inches for 10,000-volt work, but perhaps the lines have been designed for use at a higher voltage later. If the length of the span is correctly given as 100 feet, the short span and large centres should give a line practically free from any trouble, but I suggest that it is a little extravagant in cost. A most interesting feature is the cable terminations into the sub-stations, and I should like to ask if there is some particular relation between a definite length of cable termination for the two voltages, namely, 250 yards for 10,000-volt termination, and 300 yards for the 20,000 volts.

Mr. Burnand. Mr. W. E. Burnand: I think that a greater variety of electrical apparatus than is found in a big colliery like the one described in the paper would be hard to discover. The figures given on page 395 relating to the gas engines are I think very instructive. There has apparently been trouble with these large gas engines, and this I think is hardly a unique experience, although it is evidently not due to want of metal, judging by the 30 in. shaft mentioned, compared with the 34 in. diameter cylinders. I think that the course of development of these large gas engines has given rise to almost uniform disappointment. When the first of them was designed it was very reasonably assumed that the temperature of the gases on explosion would be the same as was the case with the smaller engines, and that about the same amount of heat would have to be dealt with through the cylinder walls. When, however, the engines were actually put to work, great difficulty was experienced due to overheating, of which the explanation is, as was discovered by some commission investigating the effects of gaseous explosions, that radiation played a very much larger part than was ever previously anticipated. Instead of having to deal with the same amount of heat per square inch, this, owing to radiation, was found to be more nearly proportional to the cubical content, so that not only had the cylinder walls to be thicker but a greater amount of heat per square inch had also to be dissipated. That appears to have been the stumbling block in the way of the development of large gas engines. About 500 horse-power seems to be the maximum output per cylinder for these engines at present, and that value appears to be approximately that at which the engines described in the paper are working. To have a larger number of cylinders is really to duplicate the engine. I think, however, that there are two ways in which further progress is possible. One way is to eliminate radiation or to reduce it by using a non-radiant flame. By this I mean that if the gases are mixed better, and possibly the carbon content is reduced, a less radiant flame is obtained than would be the case with a bad mixture. The difference is similar to that between

[illegible]

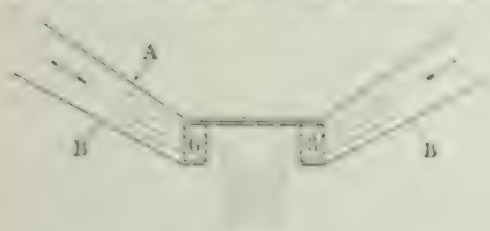


FIG. B.

through the fan arrangement as used for extracting air ; [illegible] outlet side of the fan blades, and it is increased slightly towards the outer end of the cone. As the diameter increases, the area through which the air is discharged increases at the same rate, as does the width between the cones, with a proportionate decrease in the velocity of the [illegible]

[illegible] to the half-watt lamp, I har[illegible] [illegible] stand the wash and cooling

FIG. C.

effect of the gas has to be made thick, and a thick filament [illegible] filament is at a comparatively low temperature. The half-watt lamp would be worse in that respect, so that the resulting overall efficiency might quite likely be less than is the case at present.

[illegible]

NEWCASTLE LOCAL SECTION, [illegible] MARCH, [illegible]

Mr. J. LEGGAT : In his general remarks, the author states that the question whether a colliery should generate its [illegible] a very large power-supply system exists, I think it [illegible] available at the colliery, the colliery company would find it advantageous to co-operate with the supply company and [illegible] the distribution cables which would otherwise have to be [illegible]

[illegible]

Mr. Lesson.

ends, and stand-by supply taken at such times from the power company can usually be obtained on reduced terms. In this district there are several such cases in which the surplus electrical energy generated and not used by the colliery company is sold to the power company, the net cost of stand-by current to the colliery being very low indeed. With main winders of the size of those at the Britannia pit it would probably be impossible to install anything but an Ilgner flywheel arrangement to give proper control and braking in addition to dealing with the heavy peak loads; but motor-generator or equalizer arrangements should be avoided where possible, owing to the loss of efficiency, extra complication, and first cost. A simple 3-phase alternating-current motor with liquid control and driving the drum through single-reduction gearing is a most satisfactory arrangement where it can be adopted. If supplied from a power company capable of dealing with large peaks, such an arrangement can be used in fairly large sizes. We have a case in Durham of two winders, each dealing with 189 tons of coal per hour from a depth of 450 yards, where the peaks are about 1,500 b.h.p., and the efficiency and control perfectly satisfactory. I believe these are the largest geared winders in this country. The author draws attention to the heavy duty imposed on the reversing switches on haulage controllers. In the case of the winders above mentioned we have arranged for the oil to be filtered and changed once every fortnight, and have had no trouble due to carbon deposit collecting on the contacts. The filter is installed in the engine room, and the switch tanks can be easily emptied into it and fresh oil run into the tanks in a few minutes, the same oil being used over and over again. In addition, the tanks are lowered and the contacts inspected once a day. The switches have worked quite satisfactorily since they were installed. I should like to ask the author whether he has experienced any trouble with the filter screens used in the ventilators of the pump motors at the Elliot pit. In this district we have found in some cases that screens of this kind become clogged with dirt after a few weeks' use. It is almost impossible to clean the cloth for use again, and the cost of renewing it becomes quite an appreciable item in the operating costs. Probably in a pumping installation of the size described it would pay to install a wet-air filter. The author's satisfactory experience with the Samuelson typé of exhaust-steam accumulator is interesting, as back pressure on the winders and other engines the exhaust steam of which is used has given trouble in many cases where the ordinary Rateau accumulator is installed.

Professor Thornton.

Professor W. M. THORNTON: I should like to assure the author, with reference to his mention of the attitude of the South Wales coal-owners towards safety, that in Northumberland and Durham they are equally alert, and I was recently told by a large coal-owner that, without regard to cost, they would take every step which could be shown to make for the safety of their men. With reference to small coal, which is a problem of increasing importance, I should like to ask whether the author has tried the Bettington boiler which would appear to be well suited for South Wales conditions. It must be satisfactory to all electrical engineers here to hear from the author that the Powell Duffryn Steam Coal Company generates over 30,000 horse-power for its own use. The paper is interesting on account of the variety and extent of the applications of power, including winding by continuous current at Britannia and by alternating current at Abercwmboi. The great objection to the use of electrical power for winding has been its relatively high cost when replacing steam plant. I venture to think that the paper would have been of more value to the engineers for whom it was intended if the author could have given (or could give) us some approximation of the costs both of the plant and of its operation, for in judging any engineering work it is necessary to know whether its cost is proportionate to the effects produced. I propose to leave any criticism of the constructional work to those who have had recent experience of mining plant in this district. My own interest has been chiefly in the improvement of the safety of underground mining, and in this respect the first part of the paper which calls for remark is that referring to earthing on page 399. I think Regulation 118 contemplates (1) shock from static charge, (2) shock from a fault of short duration, (3) leakage current which might cause shock during leakage. There is no doubt that during the second before the trip gear operates there can be high voltages on the earth return, but my experience of several occasions when a fault on an underground cable has operated trip gear on the switchboard is that—on multicore cables at least—there may be a dead short-circuit inside but no evidence outside except that the armouring is bent in by the blow which caused the fault. A fault of several hundred amperes on 600 volts would, I suppose, destroy a cable in a few seconds, and the fact that the trip gear or fuses have operated shows that the voltages to which the author has called attention will probably be of exceedingly short duration in practice. The dangerous voltages begin at about 100 amperes to earth. The remedy would therefore appear to be not to change the earthing requirements, except in the direction of having larger volumes of coke as the author suggests, but in having cut-outs which operate with very small time lag with less than 100 amperes leakage, not a very difficult proposition. Exposure to even a severe shock for a moment is not likely to be fatal unless there is organic weakness. An earth-plate which I described to the Association of Mining Electrical Engineers some years ago may help in the direction of improving earth connections. It consists of a conical cast-iron dish, or the end of an old boiler drum to which connection is made by a wrought-iron steam pipe about 2 inches diameter projecting above the surface and having both an electrical connection to the earthing bar and a water service. Holes in the side of the pipe keep the dish full of water and the coke in the neighbourhood always moist by diffusion. The essential feature is that there is a body of water which cannot drain away but will diffuse through the surrounding material. It may be even possible to maintain an efficient earth in-bye, in rock if drainage is prevented, though there are bound to be always difficulties in this—we might have earthing chambers of large volume underground. With regard to underground lighting by hand lamps, the Ralph indicator now reaches the desired standard, and the Philip and Steele indicator has the same possibilities. It is not too much to hope that these will soon be proved by actual trial to be more reliable than the slow and less definite safety lamp and that these will be entirely discontinued.

stant of a circuit, viz. L/r, is the period taken for the current

is equally true that some we[illegible]

le to the lead cell.

Mr. Beard.

Mr. J. R. BEARD: Although particulars are given of the installed plant capacity and annual output no mention is made of the sustained maximum load, but assuming one-quarter of the plant is acting as stand-by the load factor last year would be 39 per cent. This is lower than I should have expected for such a system, particularly as it is mentioned that arrangements have been made by which the greater part of the pumping is done on the night shift. It would also be of interest to know whether the load factor is high enough to allow of the whole of the available waste heat being utilized, and if not what proportion the surplus bears to the whole. I notice that a number of the generators and motors are wound for working direct on the 11,000-volt system, thus saving the cost of step-up and step-down transformers respectively. Does the author find that the increased security and lower maintenance costs of 3,000-volt generators and motors justifies the cost of the necessary transformers? In the diagrams of the various types of transmission lines no telephone cables are shown. Presumably these are provided, as telephonic communication between the power station and sub-stations is essential for satisfactory operation. It is interesting to note that the author has adopted the method, which has proved so satisfactory and convenient in this district, of leading overhead lines into sub-stations by short lengths of underground cable. A previous speaker has criticized the use of such a high pressure as 20,000 volts for the long interconnector. I would rather ask the author why, in view of the fact that all the apparatus is designed to be suitable for a pressure of 30,000 volts, he does not use the higher pressure in the first instance and improve his transmission efficiency and voltage regulation accordingly. One of the most interesting sections of the paper to me is that on earth-plates. There is, however, one point which I do not think is mentioned, namely, the difficulty of maintaining continuity in the connection to the earth-plate. Corrosion of this connection is particularly liable to occur at the junction with the earth-plate, especially if soldering is used, and even if the copper connection is bonded to the plate trouble is liable to develop owing to the damp surroundings. Discontinuity of the connection is difficult to discover and to repair and may lead to serious results, as nothing is more dangerous than apparatus which is supposed to be earthed and is not so. In a scheme with which I am connected it is proposed to overcome this trouble by using insulated armoured cable for the connection and terminating it at the earth-plate in a sealing end attached to the earth-plate in such a way that the whole of the sealing end and the connection to the earth-plate can be surrounded by insulating compound. By this means the only metal in contact with earth will be the earth-plate itself. An interesting point brought out by the paper is that most of the fall in potential is in the immediate neighbourhood of the earth-plate, and therefore if the latter is buried deeply there is little danger of any dangerous potential on the surface of the ground. It occurs to me that this is of particular interest in the case of the earthing of generator neutrals. The earth-plates for this purpose may have to pass very heavy currents, and it is already considered good practice to insulate all generator neutral-connections in view of the possible dangerous rise in potential under short-circuit conditions. If this insulation is carried right up to the earth-plates in the manner described above, and if in addition the earth-plates are buried at a considerable depth, the whole of the earthing arrangements will be perfectly safe. As the greater portion of the total resistance of an earth-plate to earth is not between the earth-plate and the coke filling, but between the coke filling and the surrounding earth, it follows that it is desirable for the contact surface of the coke with the earth to be as large as practicable. With the usual arrangement of earth-plates this means expensive excavation, and I suggest that this may be saved in many cases by using the excavation which is necessary in any case for buildings; for example, in the case of sub-station earth-plates—always a difficult problem—a layer of coke might be laid underneath the whole of the building foundations. As it is usual to carry foundations down to the clay the conditions would be very favourable to a good earth. It would not be necessary to bury the earth-plates themselves under the building, as the layer of coke could be continued beyond the outside walls at several places and joined up with the coke surrounding ordinary earth-plates put down in the usual manner.

Mr. Clothier.

Mr. H. W. CLOTHIER: The paper is an interesting account of work accomplished in a period during which considerable development has taken place, and the author's experiences with an account of what he would do if he had to design the lay-out and the whole plant again would be of even greater value. I realize that this is perhaps too much to expect, but I should like to ask a few questions. (1) Both water resistances and oil-immersed wire resistances are in use in series with the arresters. Which type has given the best results? (2) Would the author again install arresters in the case of a 3,000-volt circuit? Are they not the cause of more trouble than they are worth? (3) What is his experience of reverse-current relays for generator protection; (4) and also of the balanced system of feeder protection (Merz-Price)? (5) To what extent has the leakage protection mentioned in the abstract of the Regulations, 124 Section (*d*), been applied? I note that on the motor circuits only overload relays are mentioned, but I think it would be possible to make a better arrangement of the general protection underground by the use of core balance or corresponding leakage devices, if necessary having graded settings with the heaviest setting at the power-supply end and the lightest at the motor panels. By careful selection it is possible to clear faults with a very slight risk of serious interference with sound sections. Referring to the author's conclusion in regard to the signal bells and batteries, (3) page 423, the second half of the battery would presumably be inserted in about the middle of the line and not at the end, (5) and I think that a condenser across the break of the switch would be better for the purpose of eliminating sparking than a non-inductive resistance in series, although either might be dispensed with if a proper flame-proof joint, preferably a wide machined flange, be used. I consider that the alternative of using relays to close a separate bell-ringing circuit would go a long way towards avoiding the danger of open sparking, as the relay coils would have much lower self-induction and a pressure of even less than 6 volts might be found sufficient. A substantially constructed relay having comparatively negligible inductance can be made to operate with 0·09 volt-ampere on a 25-period alternating-

[illegible] and I [illegible] [illegible] curves, and tables [illegible] ...ents with earth [illegible] addition to [illegible] disconnected, the potential between the earth-plate and [illegible] will exist. In the first condition the fault current will [illegible] assumed that the cable sheath or other earth conductor is broken between the fault and the neutral point. In these [illegible] practice the resistance of the earth-plates at the neutral [illegible] portion of the resistance in the path of the fault current [illegible] fault and not at the earth-plate. In order [illegible] point may be a little clearer I shall assume the condition in which an ordinary colliery motor develops a contact between one terminal and the frame. If now the earth connection at the motor is broken, the only way in [illegible] but at the motor. The only way in which danger could be [illegible]

[illegible] that the earth-plate [illegible] would conduce to safety It must [illegible] will still have [illegible] experience a shock. However, the aut[illegible] direction. I must admit, however that if [illegible] necessary to adopt as a minimum eight earth plates no two [illegible] ments. I [illegible] particulars of the steps taken to surmount [illegible] fingers mentioned on page 417, I feel sure they will be both interesting [illegible]

[illegible]

such a sub-station may require provision to be made for a very heavy fault current, say 500 to 1,000 amperes. An ordinary pair of plates tested in series under average conditions in clay will have a resistance of from 6 to 8 ohms, *i.e.* something under 2 ohms in parallel as used; this means a rise of 1,000 to 2,000 volts with the above fault currents. In practice, however, the resistance to earth of the general metalwork of the sub-station, the cable sheaths, and the pole-line earth-plates, is much less than the "official" earth, being in several representative cases ¼ ohm. This corresponds to a maximum of 250 volts, which is still too large, especially considering the steepness of the potential gradient near the fault, very well shown in Fig. 10, so that an unsafe value of "volts per yard" may still be reached. Seeing that an individual plate is some 10 to 20 times this joint resistance of ¼ ohm, I do not see how it is reasonably practicable to reduce this latter figure much, and I should be grateful for suggestions under this head from the author. The whole question of the resistance of earth-plates is a very important one and called forth an interesting leading article in this week's *Electrician*,* which might form a basis for further discussion.

(Mr. SPARKS' reply to the discussion is given on page 669.)

BIRMINGHAM LOCAL SECTION, 3 MARCH, 1915.

Mr. R. A. CHATTOCK: I propose to confine my remarks to one or two points in connection with the arrangements made for supplying the power. Turning to the section of the paper dealing with the power stations, it is interesting to find that the gas-driven generators require 18 B.Th.U. per watt-hour against 36·5 B.Th.U. for the live-steam turbines. This difference is largely accounted for by the difference in the load factor of each type of generating plant, that of the gas plant being 72 per cent whilst that of the steam was 47 per cent. I am of the opinion that even better figures than those given should have been obtained with these load factors, but the actual performance probably would be accounted for by the fact that the plant was installed some years ago and was not quite so economical as more up-to-date plant. It is certainly very necessary to keep the load factor on the gas-driven plant as high as possible, and it is interesting to see that with mining work it is possible to adjust the load by carrying out the pumping during the night and by supplying the general demands of the colliery during the day, thus obtaining an annual load factor of 72 per cent. Some years ago I went into the question of using gas plant instead of steam turbines for ordinary electric power supply from a central station, and I am satisfied that an annual load factor of at least 35 per cent would be required before the gas plant could compete in efficiency with the steam turbine. The ordinary central station, working on a light, power, and traction load, has of course only a load factor of about 25 per cent, and the adoption of gas-driven plant is therefore in my opinion not justified in these circumstances. These conclusions are based not only on the actual cost of generation by the two methods, but also on the capital cost of the plant and buildings required. I consider, moreover, that turbine-driven plant is more reliable than the large gas engines, experience with which has not, up to the present, been entirely satisfactory. I am interested to see the arrangement of turbine-driven auxiliary pumps used in connection with the condensers. In this connection I notice that the centrifugal cooling-water pump is direct-driven by the turbine at a speed of 2,500 r.p.m. Modern practice points to the use of geared pumps for this purpose. The high speed adopted is quite suitable for the air pump and the water-extracting pump, but for the large-power circulating-water pump the lower speed would be much more efficient. I should like to ask the author for his opinion in regard to the use of geared pumps compared with direct-driven pumps for this purpose. Turning to the switchgear section of the paper, I notice that the generators are protected by means of balanced protective transformers connected between the neutral and each phase, and by time-limit overload and reverse-current devices. I agree with the use of balanced protective transformers and the reverse-current devices, but I consider that it is inadvisable to equip generators with overload attachments. These should be located only on the feeders, and the generators should be so constructed that they can safely withstand any short-circuit that may occur upon them. This can now easily be carried out in modern construction. I also notice that the feeders are protected on the Merz-Price system and by time-limit overload apparatus. I should also like to ask the author whether he has considered the use of split-conductor feeders protected on the Merz-Hunter system, as in my opinion this is very much more satisfactory than the Merz-Price system, as it obviates the necessity for running separate pilot wires.

Dr. C. C. GARRARD: In dealing with such a large subject it is of course impossible within the compass of a single paper to discuss matters in great detail. I should like, however, to ask one or two questions on subjects which are, I think, of interest. For example, the author refers to a "flame-tight" box. Now what is a flame-tight box? I was talking to a mining electrical engineer some time ago, and he assured me that the proper way to make a flame-tight box was to arrange the cover and the seating with wide machined joints, but with a gap of 1/32 inch between the two surfaces. I did not believe this at the time, and I have since had an opportunity of making some experiments at the Rhymney Valley testing station. It is necessary, in order to get a box that will not emit any sparks or flames when an internal explosion occurs, to have one which, with its cover, is as closely fitting as possible. If perfectly-surfaced joints are secured, comparatively narrow machined flanges are sufficient. One has to take into account, however, that these flanges will only be machined on ordinary machines with a certain amount of inaccuracy, and the flanges have to be made wider to balance this. Good packing, if used, is satisfactory, but for use between a box and cover it is undesirable, as it is likely to become displaced and the

* *Electrician*, vol. 74, p. 708, 1915.

[illegible]

bell signalling by bringing the two wires into contact, [illegible]

Mr. N. Shuttleworth : I propose to confine my remarks to that portion of the paper dealing with the large winders at Britannia Colliery. The Ilgner motor-generator [illegible] between no load and full load on the induction motor, so that excessive demands made on the continuous-current generator may be provided by the flywheel at the ex- [illegible] slip or minimum [illegible] per cent of the total input to the motor. The average slip in the absence of further particulars may be assumed [illegible]

[illegible] than 10 per cent or 175 h.p. of the present [illegible] per day. It would seem therefore that the direct benefits to be obtained from the use of a rotary type of regulator amply justify further capital expenditure in this [illegible]

[illegible] the close of the paper, together with th[illegible] arise from the operation of bell contacts. It is true there are many electric bells and signals to be obtained which are reliable when operated with alternating current. But [illegible] carries a single or double vibrating disc [illegible] by the intermittent attraction of a horseshoe magnet of [illegible] supply in mines, it [illegible]

Dr. Morris. sparking, without involving any increase of first cost. It is suggested by the author, however, that the principal danger is due to the use of bare wires on which contact is made to close the bell circuit; and to avoid this danger completely it would be necessary to install a large number of gas-tight bell pushes on the supply side. This should not present any serious difficulty.

Mr. Jones. Mr. CHRISTOPHER JONES: The paper shows what an important part electrical power plays in the production of coal. I regret, however, that the author has not gone into the question of the use of electrical power for the individual colliery, apart from big schemes such as that referred to in the paper. There is, moreover, a wide field for the introduction of electrical power in subsidiary haulages so as to dispense with horses or ponies, the cost of which can be estimated at £1 per week each to maintain, apart from drivers' wages. While there are many positions in pits where possibly electrical plant is not suitable or even safe, still in such circumstances electrical energy can be carried a considerable distance in-bye and air compressors operated by electric motors. I entirely agree with the author's view that the efficiency of compressed-air transmission and conversion is low in comparison with electrical transmission, and I recently found a case where a coal-face conveyer worked with compressed air required a 20 h.p. electric motor at the compressor end although with electrical drive to the conveyer 5 horse-power would have been ample. I have come to the conclusion that for a coal-cutter 100 horse-power is required at the compressor end, as against 30 horse-power with electric drive direct to the coal-cutter. These figures show the inefficiency of compressed air, but I agree that its use is very suitable for driving headers, drills, etc. The author appears to favour continuous-current motors for fans and compressors where variable speed is required, but he admits that efficiency is sacrificed and also that an increase of wear and tear takes place. For running at constant speed I consider an alternating-current motor to be a more suitable machine for mining work than a continuous-current motor. The author mentions cases where the latter type is used in-bye for compressor drives. Such motors are more liable to cause sparking as compared with alternating-current cascade or squirrel-cage motors. Indeed under the heading "Haulage Gears" the author states that it is undesirable to employ continuous-current motors—I presume for those reasons already referred to. Single-reduction gearing is an ideal drive for a haulage. Of course, as stated in the paper, such gear requires a lot of room where a large set is installed, but the decreased wear and tear and its silent operation are strong points in favour of its use. In order to avoid large, wide motor houses my firm are adopting single-reduction gear, but the drums are in tandem, narrow drums being provided. These are used for stall road motors and give splendid results. The small type is fitted with a friction clutch. Electric controllers are, however, now generally adopted. Such apparatus is portable and can be fixed by the side of the road at little cost. I agree with the author that liquid controllers are more suitable and give the best results for haulage sets, the control being so flexible. Oil-immersed resistances are advantageous where there is danger of open sparking taking place. Manufacturers could with advantage go into the question of keeping down the amount of copper used in contacts, etc., as I have found cases where a length of 15 inches of copper, 1 in. $\times \frac{1}{8}$ in., had to be "scrapped" in order to fix new 1 in. tips. This also applies to some types of finger tips which are offered. The author appears to favour slip-ring motors for small machines at the surface, on account of switchgear maintenance. This I entirely disagree with. From experience I find that a squirrel-cage motor with star-delta or auto-starter switches is less troublesome than to use liquid starters with unskilled labour. All the above are fool-proof, and this is a point in favour of the squirrel-cage motor for such work. I am using a large number of such motors, and the cost of switchgear maintenance has been practically nil for the last 5 or 6 years. I make use of the 110-volt lighting supply for motor houses, pit bottoms, and at important junctions on the main road, this supply being obtained from small transformers. This increases the safety, as the provision of plenty of light in a coal-pit is a very important factor. With reference to overhead transmission, bare conductors are a very reliable source of supply but require protection at important roads crossings, etc. Inefficient screening is entirely dependent upon the earthing of such screens. I prefer the use of suspended cable for such places. The cables were 3,000-volt paper-insulated, leadless, and covered with bitumen in the case of sizes larger than about 7/18 S.W.G. I should like to ask the author whether he has experienced any trouble with suspended lead-covered cables. My experience is that the lead cracks at the point of suspension, *i.e.* near the pole. I should also like to ask the author why he adopts a particular length of cable from the sub-stations to the overhead lines, and why he did not use cable for his 20,000-volt line crossings as he used cables at the pit surfaces. With reference to earthing, the records of the author's test are very valuable and in general I agree with them. I consider it essential to earth at points other than at the surface in some cases, but surface earthing is without doubt the proper thing to do. I agree that the advantages claimed by the advocates of insulated neutrals are nullified by the rule that a faulty circuit must be made dead when a fault occurs, and I also agree that with the neutral point earthed and by the use of protective gear greater safety is obtained. The author is fortunate in having armoured cables throughout. It is the best system to install and the use of duplicate feeders is very good practice from the point of view of reliability of the supply. The earth conductor is best arranged as an integral part of the cable. I should like to know the author's views in regard to the size of earth conductors in low-tension systems supplied from, say, underground sub-stations fed at a high pressure. I introduced high-tension cables with armouring capable of carrying 50 per cent of low-tension in-bye conductors. I should also like to ask the author whether the cables are protected by Merz-Price gear and if the cables underground are buried or are suspended. I cannot but admire the thoughtfulness of providing for the future in the Powell Duffryn scheme; it is a very important feature and one that all of us might follow with advantage. The tests carried out with electric bells are interesting. I wonder what results would have been obtained if a single-stroke bell had been used for these tests. I am pleased

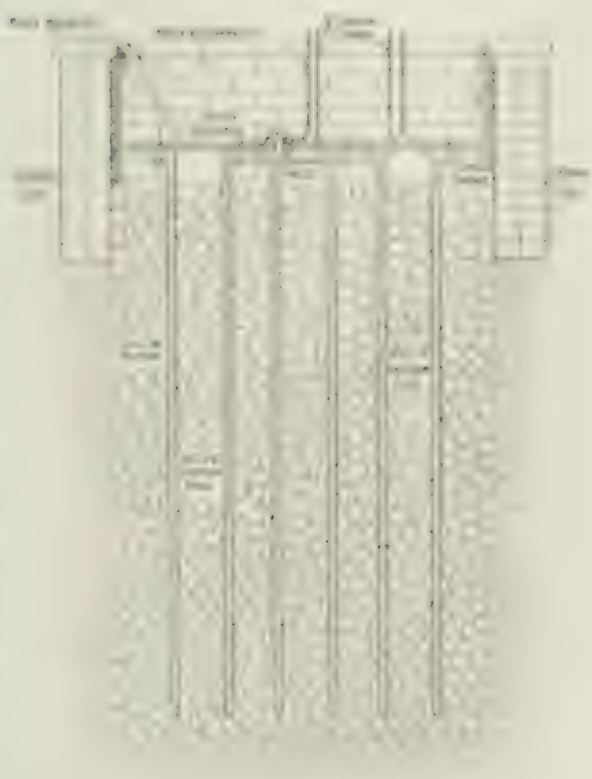
[illegible]

Birmingham Local Section, [illegible] March, [illegible]

[illegible] six inches per annum and that the [illegible] foundations are sinking at that rate?

[illegible] especially that part of it relating to earthing, and I think I [illegible] very remarkable thing that nearly all the fatal accidents due to electricity below ground have occurred, not on unearthed [illegible] ance of earthing. Speaking generally, it is correct to say that this was effected by simply putting a single 18 in. square earth-plate into the ground. If an electric bell could be rung through it, it was considered to be satisfactory. The plates used for the purpose were almost invari- [illegible] rapid [illegible] they were [illegible]

[illegible] this property are, in my opinion, perhaps not sufficiently [illegible]



[illegible]

[illegible] must remember that the memorandum is, after all, only an [illegible] quoted, under which the plates must not be [illegible]

Mr. Anderson

motive force, not exceeding 4 volts, shall suffice to produce a current of at least 2 amperes from one earth connection to the other through the earth, and a test shall be made once in every month to ascertain whether this requirement is complied with." This test is a very difficult one to satisfy, and in connection with it I should like to show a couple of slides demonstrating a very effective device which I have been advocating in connection with colliery work for several years, especially in cases where the surface conditions were bad. Fig. D depicts a group of cast-iron pipes driven vertically into the ground filled and surrounded with coke or breeze. Their flanges are allowed to remain 6 or 8 inches above ground-level and are surfaced to make good contact with a copper busbar bolted to them, from which busbar the connections to machine carcases and armouring are taken. The arrangement, which should be installed in duplicate or triplicate in the colliery yard, should be walled-in to concentrate moisture, which should be allowed to drop from engine cocks or exhaust water-pipes. Through the kindness of the Clifton & Kersley Colliery Company I have been able to obtain yesterday's (and previous) readings in connection with the plates described, which are as follows :—

	25 Sept., 1913	22 May, 1914	23 Nov., 1914	8 March, 1915
	Ohms	Ohms	Ohms	Ohms
Test between 2 sets of pipes 30 ft. apart immediately outside generating station	2·6	5·4	4·0	3·6
Test between one set of pipes and turbine bed and condenser	2·6	2·6	2·9	2·65
Test between the second set of pipes and turbine bed and condenser	—	3·2	2·7	2·65
Test between both sets of pipes in parallel, and turbine bed and condenser	1·5	1·54	1·57	1·48

It will be noted that the resistance varies from time to time, the above being the extreme readings over a period of 18 months. The nature of the ground is solid clay. These are remarkable figures and show the great difficulty, even where every care is exercised, of securing a sound "electrical contact with the general mass of earth." It is to be regretted that the author did not give us more information about the continuity of metallic sheathings and bonds. Under the new regulations most metallic sheathings have to have a continuity of 50 per cent of the largest conductor enclosed, and this continuity should be absolutely unbroken between the generating station and the gate-end box. In my experience one seldom finds an installation on which these conditions obtain. The rule is almost invariably broken at joints, owing to imperfect design, failure to recognize the difficulties of making bonds of low resistance under mine conditions, and neglect in making sufficiently searching tests on completion of the work. In conclusion I think the author is to be congratulated upon his advocacy of earthing the neutral. It is courageous of him to be so definite on a point on which there is so much divergence of opinion. There can, however, be no doubt that he is absolutely justified in advocating this very necessary precaution.

Mr. Brown

Mr. G. M. Brown: The Powell Duffryn Company's property appears to be an ideal one for complete electrification, and the first step in this direction is probably seen in the equipment of the new Britannia Pit at Penallta. With proper precautions in the design and lay-out of such a plant it should be possible to bring transmission costs down to a low figure, although the greatest drawback to a colliery load from this point of view is the low average power factor. The author states that in the Aberdare Valley the power factor lies between 0·7 and 0·85, but in all probability it is more often near the lower figure. This is quite inevitable in colliery work on account of the necessity of having the haulage motors of ample capacity for their work and with very liberal air-gaps, but the results can be obviated to a very considerable extent by the use of phase advancers, synchronous condensers, or even static condensers. The advantages to be gained by the use of suitable plant for the maintenance of a good power factor are evident, and the cost is not excessive. The cost of phase advancers per wattless leading kilovolt-ampere introduced into the line may be about 10s., for synchronous condensers about 30s., and for static condensers about 40s. This is very much less than the cost per kilovolt-ampere of the necessary generators, transformers, and cables for generating and transmitting wattless currents. The Powell Duffryn system has generating plant of 24,000 kw. capacity, and the author gives the annual load factor as 55 to 60 per cent. The power factor is presumably between 0·70 and 0·75, so that the average wattless load is between 10,000 and 14,000 k.v.a. What this involves in the way of transmission losses can only be estimated roughly, but if we take the particulars of the overhead lines as given by the author, allow normal current densities throughout, and estimate the losses due to the transmission of this so-called watless load, we find that it represents a capital value of very many thousands of pounds. If to that we add the probable cost of generators and transformer capacity required to deal with this load, the total becomes truly astonishing, and demonstrates that an investment in plant for improving the power factor on the transmission lines at least would be a sound financial proposition. The results of the author's "earth" tests form a strong argument in favour of compulsory and efficient earthing of the neutral points of 3-phase systems. I have always regretted that the Departmental Committee did not adhere to their original intention and make the use of leakage protective devices compulsory also; for even with perfect earth connections and cables armoured in accordance with the regulations it is possible to get dangerously high potentials in the neighbourhood of faults. It is to be hoped that the author's figures will accelerate progress in these directions. The Penallta winding gear is interesting in that it is the largest plant of its kind hitherto installed in the United Kingdom. The arrangement of flywheels, couplings, and clutches seems somewhat complicated and expensive, and it is not evident why the winder motors should be fitted with double commutators; the current per brush stud is only 370 amperes, and could easily be collected from a commutator of normal construction. Neither is it evident why there should be both magnetic

[illegible] to interlock the controller and depth indicator, and the [illegible] of controller can be adjusted to give the proper rate of acceleration under normal conditions of load only, [illegible] especially in cases where it is necessary to apply counter current to bring the gear to rest at the end of the wind or in case of emergency, for the reason that if the stator switches should be quickly reversed before the [illegible] of the motor drawing an excessive current, opening the circuit-breaker and so taking the control out of the driver's hands just when it is most essential that he should retain it. The success of this type of controller at Aberewmboi is probably due to the fact that the weight of the loaded cage and rope is greater than that of the unloaded cage and rope throughout the wind. The amount of air required for the ventilation of the large high-speed motors now used for driving centrifugal pumps is very great; for [illegible] will probably require about 10,000 cubic feet per minute. These large volumes of air necessarily carry with them a quantity of dust, some of which will accumulate on the windings and in the ventilating ducts of the motors and ultimately cause breakdown. The example set by the [illegible] thanks are due to the author for bringing it into prominence. There seems to be a very general impression [illegible] in oil must necessarily result in considerable reduction in wear and tear of the fingers and contacts. The oil, it is true, quickly suppresses any arcing that may occur on opening circuit, but it also has the effect of [illegible] in excessive pitting and deterioration of the contacts [illegible] and it is [illegible] metallic type would result in even lower [illegible] author.

[illegible] There is a possibility of half-watt lamps being available for this purpose though not in the near future. There are very great structural difficulties to be overcome before they can be manufactured commercially. At first their [illegible] rather than in reduced current [illegible] present in use will be improved in the [illegible] creased current consumption. One point in connection [illegible] of considerable importance in reference to the cost of renewals. That is the voltage at which they are used. One-tenth of a volt seems very small and insignificant especially to those who are accustomed to thinking in [illegible] in the case of a 2-volt lamp, and it represents a difference of nearly 50 per cent in the life of the lamp and about 20 per cent in the candle-power that it gives. There is a considerable difference in the average voltage during discharge of different makes of lead accumulators, and this average voltage varies according to the time that is allowed to elapse before recharging [illegible] when the cells are recharged after 14 hours' use will have [illegible] is recharged after eight hours will be decidedly dim at the end of 14 hours' discharge. Therefore it is really quite [illegible] of them.

[illegible] electrification of collieries in Lancashire is concerned the whole or very nearly the whole field has yet to be attacked. I propose to confine my remarks to the power side of the

Mr. Watson. subject. In the first place I am very much impressed by the fact that three principal sources of power are employed at the Powell Duffryn collieries, viz. live steam, exhaust steam, and gas. If it had been possible to give figures regarding the cost and working expenses of the three different forms of power it would have added very considerably to the interest which many of us take in the paper. At the same time one realizes that it is impossible for the author to go closely into details on those matters. In connection with the exhaust-steam mains shown in Fig. 5, I would ask what is the greatest distance that it has been found advantageous to carry the exhaust steam to the accumulator. It would appear from Fig. 5 that some of the lengths are appreciable and I should imagine there are serious losses. With regard to the gas-engine question, there is not the slightest doubt that it is a thoroughly good proposition to employ them at a centre where coke ovens are already established. No doubt some members have visited the large Continental centres and have observed the extent to which large gas plant has been introduced, particularly in Germany and also in France, for using coke-oven and blast-furnace gas. Such a prime-mover is undoubtedly a practical piece of apparatus, and although the first cost is high it must be a much more efficient way of utilizing by-product gas than burning it under a steam boiler for the purpose of driving turbines as is done in other cases. There is no doubt that the gas engine has a very much higher thermal efficiency than any type of steam prime-mover which has been introduced. There is a small point which may be of interest and which nobody has yet raised. On page 393 the author mentions a hand-regulated static booster. I should be interested if he could add any further information about the design or type of the apparatus referred to. Then again I find there is no mention of the use of coal-cutters in any of the pits. I am not very closely acquainted with colliery work but I have always understood that was a purpose to which electric motors could be very well applied. The author mentions in connection with a transmission line only 9 miles long that he found it necessary to increase the pressure from 10,000 to 20,000 volts. I should hardly think it was necessary to go to such a high pressure for such a comparatively short line. Were there any other reasons which led to that course being adopted? On page 397, referring to the poles for the overhead lines, the author mentions that the conductors are carried on pin-type insulators mounted on three channel irons, 4 inches by $2\frac{1}{2}$ inches, these being protected by insulated sleeves so as to prevent birds operating the protective gear. I do not quite understand how that insulated sleeve is used and I should like to hear an explanation of it.

Dr. Worrall. Dr. G. W. WORRALL: I have been very interested in the author's remarks on the earthing system at the Powell Duffryn Collieries. I superintended recently some measurements of the conductivity of the earthing system at a large group of collieries and found that it varied between 1 and $2\frac{1}{2}$ times the conductivity of the cable core; this included joint boxes and switchgear in circuit. The actual value varied with the size of cable. The tests are not yet complete, but so far only one fault has been discovered, and that was in an earth pin at the end of a trailing cable. A question often arises as to whether the armouring of a high-tension cable down a pit shaft is a sufficient connection between the armouring of the low-tension system in the pit and the earth-plate on the surface. Strictly speaking I suppose it is not, but perhaps the author can tell us what is intended by the rules. Several years ago I made some tests on the earth-plates of a number of lightning conductors and with one exception found that the resistance of each plate did not exceed 1 ohm. The exception was the main earth of the conductor attached to a chimney, and on investigation it was found to be buried in the concrete foundation. It is some years since I made the measurements, but I remember that the warehouse was near the Liverpool docks and that the plates were sunk in sand through which the sea-water percolated at high tide. In visiting collieries of various sizes I have found that the electrical equipment is very satisfactory when properly installed; but many colliery managers seem to think that a haulage motor, particularly if it is only of 20 or 30 horse-power, can be installed by cutting a hole in one side of the road and putting the motor there. That is not the way to equip a colliery, but even large collieries adopt that system and refuse to make any improvement. Such procedure no doubt accounts for the bad reputation electricity has in the minds of the majority of miners. A short time ago I saw the engineer of a very large group of collieries who advocated the abolition of all starting gear underground. He simply switched the motors straight on to the mains. The motor that we happened to be discussing was of 40 horse-power and he had a special design in which the stator coils were well secured. He said the results were very satisfactory. I should like to draw attention to one point which seems to be missed by many lamp makers. They make the electric lamp very similar to the ordinary miners' lamp, so that if one is following a man who is carrying such a lamp it is very difficult to watch the road. If they would put a reflector on the lamp it would be more satisfactory. Of course there are many types of lamp in which the light is properly shielded. With regard to the use of hide thongs for suspending cables, we had trouble at an underground stone pit through the thongs being eaten away, presumably by rats, and we had to substitute zinc thongs. Rats are found in every pit and I wonder whether anyone has had a similar experience.

(*Communicated*): Since the above remarks were made, Mr. W. T. Anderson has sent me a copy of his paper on "Colliery Cables" read before the Manchester Geological and Mining Society in 1913. In this paper Mr. Anderson asked the same question regarding the earth connection to the surface, and Mr. Nelson in the discussion remarked, "Mr. Anderson had mentioned the matter of the proper section of the high-tension armouring where the current was transformed down at the shaft bottom, or elsewhere, for use in-bye. It should be remembered, as he (Mr. Nelson) believed someone had already pointed out, that the difficulty did not occur when the neutral point in both systems was earthed. To meet an insulated neutral point —the case of the 'conscientious objector' to an earthed neutral point—there was an alternative to Mr. Anderson's suggestion, namely, to fix an earth-plate or plates at the junction of the two systems and to connect it, or them, in parallel with the surface earth by means of the armouring of the high-pressure cable alone, or, if the circum-

[illegible]

[illegible] minute there will be much more likelihood of corrosion than if it is run at, say, 1,000 revolutions. Therefore if it is desired to use small steam turbines for driving these [illegible]

Mr. C. H. [illegible]: Most of us know the changes that have taken place in the use of electricity in collieries of recent years, and when one reflects that only 10 years ago some colliery engineers thought it absurd to discuss the use of the exhaust steam from their winders for power pro[illegible] tion of 50 periods. [illegible] particularly in connection with the question of speed-ranges. Another advantage, particularly from the manufacturer's point of view, is that this frequency fits in with [illegible] point also from a colliery point of view, as electric motors [illegible] the electrical staff at collieries is very important. A colliery [illegible] often to a man who in view of the small size of the colliery cannot be adequately paid and therefore cannot have the experience to deal with such a valuable collection of machinery. From that point alone it is an advantage for [illegible]

[illegible] tions with the spray. In the [illegible] the power station I particularly noticed the [illegible] to impress upon some colliery engineers—the [illegible] installing and [illegible] Another point that I desire to refer to is the quest[illegible] specification of the power factor and [illegible] motors. The [illegible] plant should [illegible] would save many of the [illegible] with motors in [illegible] to impress this point upon a colliery manager, especially [illegible] the coal dust is of no consequence; but there is not the [illegible] have to be [illegible] would spend a little more time in the design a[illegible]

Mr. Nelson. remove a great deal of the trying time that an engineer sometimes experiences below ground. After all it is not a very nice thing to move a motor at all from a very awkward position under ground, without having trouble in detaching cables. Lastly, the author's researches on the conditions in signalling circuits are most valuable, and his oscillograph curves of the induced voltages in signal circuits when the circuit is broken are very instructive.

Mr. McKinnon. Mr. E. C. McKinnon: In the section of the paper dealing with lighting I notice the statement that while 40 lead batteries are assembled in a group for charging from a 110-volt circuit the number of alkali cells is only 26. This latter number appears so small—signifying a counter electromotive force of 4 volts per cell—that I think the figures must have been reversed and should read 62. A life of 9 months from lead positive plates seems so extraordinarily low, representing as it does probably not more than 200–250 discharges, that the explanation is worth investigation. Such a short life may be accounted for by too much charging. The author mentions that the batteries used to be charged in 7 hours, but that the charge is now extended to 12 hours. Does this mean that the rate of charge has been decreased, or that the extent of charging has been increased? Charging at a decreased rate would tend to increase the life of the battery, but unnecessarily extended charging at any rate would cause the plates to deteriorate. One contributory factor is probably found in the statement that the energy required for charging is of minor importance; very probably the life of the plates was affected by giving them too much charging. The use of celluloid separators between the plates has been proved to cause deterioration. Treated wood separators on the other hand hold the active material in position in the positive plates, and prevent internal short-circuits, and in cells thus equipped there should be no difficulty in obtaining at least 600 discharges from one set of positive plates. The output of the cells would be affected by the volume and specific gravity of the acid, but now that a non-spillable accumulator is available the difficulty with free acid has been overcome, and the elimination of celluloid separators permits of the use of sulphuric acid with a high specific gravity.

Mr. Cooper. Mr. A. G. Cooper: I had some experience in colliery work about 16 or 17 years ago, when of course continuous current was more generally adopted for colliery installations than it is to-day. One or two of my experiences might be useful to people who are still using continuous current, if there are any. I installed two 50-h.p. haulage gears—they were only small auxiliary gears—and two of the conditions were that the motors were to be gastight and that the temperature rise was not to exceed 80 degrees F. at the end of a six hours' run. Those conditions were found to be very difficult to comply with, and one eminent firm of motor makers had to give the problem up. Eventually, motors were installed which would probably be rated at about 125 horse-power above ground. Then the trouble was to make them gastight, but this was found to be practically impossible as they had to work with a pulley. In the test that I was able to carry out, we got 4 inches of water draught by continuous pumping; but as soon as we stopped pumping, the air leaked through the bearing. One of the principals of the firm suggested that it would be a good thing to build a sort of cooling coil in the main air-way, and to circulate the air so as to keep it as nearly as possible at one temperature in the motor case. But even if the motor is made as nearly gastight as possible, the heated air on cooling contracts, and air charged with gas may be drawn into the motor case. In another instance compressed air being already installed was utilized in order to keep the motor clear of gas and cool, a small quantity of compressed air being allowed to pass into the motor case and out again. It helped to ventilate the motor and had the desired effect of excluding gas. With regard to the question of earthing, some years ago at Bournemouth I remember a horse being killed by stepping on a manhole cover. That was due to the difference in potential between the cover and the surrounding earth. Thus in earthing on the surface, even if we obtain a good earth it is still possible for there to be a considerable difference of potential in the mine. We were also troubled in this particular colliery with induction. The switchgear was tested on the surface and was found to be perfectly satisfactory, but when tried in the pit it would not break the current. I take it that was due to the armouring of the single-core cables, which were over three miles in length, lead and return, so we had to adopt other means to quench the spark.

Mr. Cramp. Mr. W. Cramp: On page 391 the author says that it might pay a colliery to take energy from a local power station. I can hardly imagine a case in which this would be true. With such load factors as obtain in collieries, with gas often available and small coal very cheap, I cannot believe that it could pay to buy current. I wish that the author could give us comparative figures of generating costs at the Powell Duffryn pits, even if the actual figures are withheld. I have come across gas engines running in collieries wherein the chief item of expense, apart from labour and capital charges, was oil. This may often be the case, especially with large horizontal gas engines, and it would be interesting to know the cost per unit of lubricating oil to run the Powell Duffryn engines. There are few published figures of efficiency of steam accumulators, and it would be useful to know what sort of efficiencies are obtained on those referred to on page 394; that is to say how much heat is actually lost in the accumulator itself. On page 395 the calorific value of the gas is referred to. It at once occurred to me to enquire whether the author had had any trouble with pre-ignition. It is fairly well known that with coke-oven gas of 410 B.Th.U. serious pre-ignition occurs, particularly during long overloads. The difficulty seems to be due to the fact that the engines are designed for compression corresponding to gas with a smaller hydrogen content. The author has mentioned to-night that he has had trouble with pre-ignition and for that reason the power of the engines has had to be written down. Now there are other ways of getting over this trouble. One is reduction of compression at heavy loads; and another is an arrangement which mixes the air with a certain amount of the exhaust gases ejected from the cylinder, thus reducing the richness of the mixture and preventing pre-ignition. It would be interesting to know whether these methods have been tried by the author, and also what system is adopted for removing tar from the gas. Again it would be interesting to know why for 1,000 k.v.a. sets the low-speed engine is adopted at all. The capital cost per kilowatt is much greater than that of the high-

[illegible] the blocks caused them to conduct more freely. I do not understand how the author obtains improvement in power factor due to the Tirrill regulator. If the Tirrill regulator were put in a rotary-converter circuit it might improve the [illegible] be necessary. If the passages near the pump-room are [illegible] or 6 inches is required to draw the air through [illegible] high, or else power is being thrown away in velocity head. The haulage diagrams do not seem to be quite clear. Is the motor relied upon entirely for control, or is there a clutch? In the latter case can it be put in easily and taken [illegible] know what the rope speed is in the main and tail [illegible] I should like to know whether constant-power pumps have been installed, and if not what the characteristics of the pumps are, and why they were chosen. Recently there has been a tendency to adopt the constant-power pump, but there is a disadvantage about it which one discovers directly one is short of power; for the demand [illegible]

[illegible] pit and in pump [illegible]

[illegible] that the [illegible] with a [illegible] not [illegible] denser when the circuit is [illegible] be a sudden rush of current across [illegible] the bell, [illegible] rid of the spark at the contacts of [illegible] A [illegible] "break" on the contact breaker is [illegible] current at the instant of break does [illegible] the case the current through the [illegible] current that was flowing in the [illegible] on the non-inductive resistance [illegible] contact. I found resistances [illegible] tive in getting rid of sparks in [illegible] course the actual resistance depends on the bell [illegible]

Mr. [illegible] power-factor [illegible] will probably be [illegible] some of the larger [illegible] installation of [illegible]

Mr. Hunt. material improvement in the power factor. Low-speed induction motors must have comparatively low power factors, and in order to work as high as possible on the power-factor curve, their maximum overload capacity is generally lower than that of high-speed machines. The application of an exciter to such a machine will not only have a marked effect upon the overall power factor of the system (if the machine be large) but will also considerably increase the pull-out torque, often a matter of considerable importance. As an illustration of this I would mention the application of a Kapp vibrator to a motor-generator on traction service. The motor, a low-speed one, will carry a maximum load of 770 brake horse-power before pulling up, and its maximum power factor at 400 b.h.p. is 0·87. A vibrator connected to the slip-rings increases the maximum brake horse-power to more than 1,600 b.h.p. and brings the power factor to unity over a wide range of load. The alternating-current exciter is a very valuable machine but it would appear to be a mistake to use it where a low leading power factor is wanted. For unity or perhaps 0·95 leading power factor the induction motor and exciter is an ideal combination, but for lower power factors, *i.e.* where much magnetizing current is to be supplied to the system, the synchronous motor with a continuous-current exciter is the cheaper machine. The reason is very simple but does not seem to be generally understood. Consider two machines, one of the synchronous and the other of the induction type, and let both have exactly similar stator windings; in fact let them be duplicate machines. The first motor will have a continuous-current exciter and the second an alternating-currrent exciter, or phase advancer, and when operating on the same system, loaded to the same extent and excited for the same power factor, the magnetic fluxes of the two machines will be the same. The machines work in a dual capacity; they run as motors receiving energy current from the system and act as converters changing the frequency of the magnetizing current they receive from the exciters to the frequency of the supply. With a continuous-current exciter the rotor must run at synchronous speed and the transmission of the magnetizing current to the stator is entirely due to the mechanical rotation of the poles. With an alternating-current exciter the transmission is partly mechanical, due to the rotation of the rotor, and partly electromagnetic due to the rotation of the magnetic field at the speed of slip. Only the transmission due to the rotation of the magnetic fields generates an electromotive force in the rotor winding, so that for small slips the number of volt-amperes required to overcome the self-induction is small. When, however, a machine is required to work with a low leading power factor, *i.e.* to supply magnetizing current to the system, the current in the rotor is very largely increased and with it the slip. Under such conditions the number of volt-amperes required to balance the self-induction of the windings is greatly increased and the exciter becomes very much more expensive than the continuous-current exciter which has only to supply the voltage due to the drop of pressure in the rotor resistance. To sum up; for unity power factor the phase advancer has the advantage, but for leading power factor the synchronous motor with continuous-current exciter is the cheaper machine. There is another point to which I should like to refer in connection with this subject, viz. the coupling of exciters to existing induction motors in order to obtain leading power factors. Disappointing results have sometimes been obtained because the fact has been overlooked that a leading power factor of say 0·8 requires a magnetic flux considerably larger than that for which the machine was originally designed. I know of cases where it has been quite impossible to obtain the power factor expected, not because of any fault in the exciter but simply for the reason that the area of the rotor teeth was insufficient to carry the necessary additional flux. If an existing motor has highly saturated teeth it is useless to try to use it to any large extent as a medium for the supply of magnetizing current. The author refers in the paper to the use of "Cascade" motors for driving compressors and fans, and I should like to supplement his remarks by giving some information concerning the speed variations which can be obtained. For fan-driving the range of speed required is generally considerably less than the range desirable for an air compressor, and in most cases two speeds in a ratio of 3 : 2 with rheostatic control for intermediate speeds, or for speeds below the second one, often meet the case; recently an intermediate speed has been found possible, and this is often useful. In the case of a motor wound for say 12 and 18 poles, an extra speed corresponding to either 14 or 16 poles can be introduced. For compressor-driving 3-speed motors are often used, the speeds being in the ratio of 6 : 3 : 2. By making use of the extra speed mentioned above, the regulation is made more uniform, and, for example, speeds corresponding to 12, 18, 24, and 36 poles can be obtained. In the 3-speed motor there is only one winding in the stator and one in the rotor, and the only complication introduced in obtaining the fourth speed is the addition of a second winding in the stator. Where economical speed regulation is not required, the machine can be run at its "Cascade" speed only and then no slip-rings are necessary. By the use of a motor of this construction haulage gears, etc., can be driven by motors having windings which are practically equivalent to squirrel-cage construction.

Mr. Foster. Mr. LLEWELLYN FOSTER (*communicated*): I notice that the author makes no reference to the question of breakdown in connection with the electrical plant at the Powell Duffryn collieries. In such a large plant, having over 500 motors in constant work, it would be interesting to know what breakdowns have been experienced and what these have cost to repair. There was, I know, a failure of one of the turbo-alternators a few months ago, and possibly this failure may have been due to some weak construction which has now been improved upon. All such matters are of much interest to anyone engaged, as I am, in the insurance of electrical machinery. My company's experience, extending over 16 years, shows that the cost per breakdown of alternating-current motors is greater than with continuous-current motors, although the percentage of breakdowns is less in the case of alternating-current than of continuous-current machines. It would be interesting to know what steps the colliery electrical staff take for noting the radial air-gaps of these motors. Radial air-gaps are now cut down to such a small figure that it is essential there should be some ready means of viewing the air-gap whilst the motor is

[illegible]

of electricity, although the average depth of wind had increased to 400 yards; while the pumping requirements, due to unwatering of districts previously unworkable, had [illegible] coal consumption had been reduced from 300,000 tons to [illegible]

[illegible] one shift of 8 hours per day, and in view of existing legis- [illegible]

[illegible] for the spare plant held in reserve, for pumping and venti- [illegible]

[illegible] of individual pits are often relatively low; this is [illegible]

[illegible] Under the conditions given in the [illegible] kilowatt-hour at full load. The liberal su[illegible]

[illegible] plant in use in the P[illegible] been possible to st[illegible]

[illegible]—In my opinion air filtration is the most valuable accessory that has been introduced for many years for improving the reliability and output of colliery plant, but due regard must be paid to local conditions.

Mr. Chattock refers to the drive of the auxiliaries at the Penallta Colliery. In this instance, the circulating, air- and water-extracting pumps are driven by an auxiliary steam turbine at 2,500 r.p.m. From the experience gained with this plant I am of opinion that it is desirable to drive the circulating pumps separately, and I prefer this method to that of driving all pumps from one auxiliary turbine, even if the circulating pumps be gear-driven.

In reply to Mr. Day, the desirability of using low-speed circulating pumps in order to avoid corrosion is an additional reason for such pumps being separately driven.

(*b*) *Use of exhaust steam.*—Mr. Scott wishes to know what is the storage capacity of the low-pressure steam-receiver at Bargoed. He correctly estimates it at 30 seconds with full load on the turbine. It must be pointed out that in this case three main winders, the steam compressor, and the fan engine exhaust into the low-pressure system, so that owing to diversity between three variable and two constant-running engines there is no necessity for large storage. With regard to the back pressure on the winding engines, the point made is that the back pressure in the case of the Samuelson type of holder is only $\frac{1}{2}$ lb. as compared with $2\frac{1}{2}$ to $3\frac{1}{2}$ lb. on the Rateau system. If an additional back pressure of 2 to 3 lb. be put on the exhaust of the winding engine the time of the winding cycle is increased. It is, of course, impossible for any storage system to reduce the back pressure due to the engine exhaust-ports. As mentioned during the discussion, this is the first application to my knowledge of the utilization of low-pressure steam where the increased back pressure has been sufficiently small not to affect the winding cycle, as compared with a free exhaust to atmosphere.

Mr. Watson asks for the maximum distance over which it has been found economical to carry exhaust steam. While the losses from friction and radiation are often high, it must be remembered that exhaust steam if not utilized in this way would be lost, as it is not practicable to have an independent exhaust or mixed-pressure steam generator operating on an independent unit, owing to the complication that would arise with a number of small units and the high capital and labour costs.

Mr. Day finds that in 100 applications of exhaust-steam utilization 75 per cent of the condensing plants are of the jet type. In the work which I have carried out the percentage is 70. With regard to the general design, I am in entire agreement with Mr. Day as to the necessity of simplicity for exhaust-steam utilization plants

Mr. Nelson raises the question of surface and jet condensers. The principal reason for using a surface condenser with the Penallta exhaust-steam plant was to obtain suitable boiler feed, but owing to the difficulties arising with surface condensers combined with exhaust-steam utilization plants, my present practice is to use jet condensers.

In reply to Mr. Cramp, I regret that it is impossible to give the efficiency of the steam accumulators used. Having regard to the large quantity of steam passing, tests of this nature are extremely difficult. It must, however, be pointed out that the exhaust steam if not utilized in this way would be wasted and, therefore, even with low efficiency there is a material gain by using even inefficient steam Mr. Spar
accumulators.

(*c*) *Gas engines.*—In reply to Mr. Selvey, the gas engines at Bargoed are always operated with coke-oven gas. The test figures referred to are for this gas, and no tests have been made on the plant with producer gas. I agree that Mr. Selvey's figure for the thermal efficiency of a modern 5,000 kw. steam alternator, viz. 20·3 B.Th.U. per watt-hour, represents present-day practice; this figure is comparable with the figure of 12·8 B.Th.U. obtained from the 1,500 kw. gas alternator with coke-oven gas. The first equipment in the Rhymney Valley consisted of steam reciprocating sets which now form the reserve plant referred to on page 393. The next generators set to work were the exhaust turbines at Elliot Pit. In the first instance, the gas-engine plant was run in parallel with one reciprocating-engine set of 750 kw., and either one or two 500 kw. turbo-alternators. The contractors for the gas engines and alternators were responsible for the parallel running of the gas-engine plants with one another. No difficulty has been experienced in the parallel running of the combination of the various units described.

In reply to Mr. Burnand, since the larger gas engines were put to work at Bargoed the horse-power per cylinder for low-speed engines operating with coke-oven gas has been increased from 500 to 1,000. While there have been difficulties, as I pointed out in the paper, this gas-engine plant has been sufficiently successful to be extended on two occasions, while an additional unit of 1,500 kw. capacity is under consideration.

Mr. Chattock refers to the thermal efficiency obtained. The result obtained on test with the larger gas engines on full load was 12·8 B.Th.U. per watt-hour at the switchboard, as against an annual average of 18 B.Th.U. per watt-hour. The lower average thermal efficiency obtained is due to the plants being worked as stated in the paper well under the maker's normal rating. The first gas-engine plant was erected in 1907, the second in 1908, and the third in 1909. From the experience obtained it would be possible, as pointed out by Mr. Chattock, to obtain with a modern plant results substantially below 18 B.Th.U. per watt-hour. With regard to the annual load factor at which the use of gas plant is advantageous as compared with steam plant, this depends amongst other factors upon the relative cost of fuel and gas. In a colliery district this figure would rarely fall below a 50 per cent load factor.

In reply to Mr. Cramp, the gas engines were designed for use with coke-oven gas, the question of mixing air with a proportion of the exhaust gases was considered, and it was decided not to adopt this method but to work with low compression. The reason for the reduction in rating pointed out by the author was not due to pre-ignition, but to the cost of repairs. There has been little trouble with pre-ignition, although, as pointed out by Mr. Cramp, pre-ignition is produced by running the engines for any long period on overload. With regard to the size of the unit, although the first gas-engine set was rated only at 1,000 k.v.a., when this set was ordered it was decided that if satisfactory results were obtained units rated at 2,000 k.v.a. should be used for the extensions. At the time this plant was ordered (1906) no high-speed gas engines of such output of English or Continental manufacture were offered. For further extensions high-speed engines are under considera-

[illegible]

booster controls the power factor between the generators [illegible]

[illegible] pressure of 6,000 volts. Consideration of this matter would show that it would not be commercial to transmit 6,000 k.v.a. at the lower pressure for a distance of from [illegible] gear is not the determining factor. In this instance no [illegible]

In reply to Mr. Beard, the present power requirements render it unnecessary to operate at a higher pressure than 20,000 volts, but in view of the increasing output of the [illegible] With [illegible] his question as to telephones, [illegible]phone system connecting the stations and sub- [illegible]

In reply to Mr. Clothier, the paper deals with the position which has arisen in erecting plant over the last twelve years: this is [illegible] immersed wire resistances in series with arresters, as the liquid in a water resistance is always liable to evaporate. [illegible]

[illegible]

Mr. Chattock raised the [illegible] Since the development of the Merz-Hunter [illegible] feeders. Reference to page 307 of th[illegible] on the Merz-Hunter [illegible]

Mr. Jones refers to trouble th[illegible] of lead-covered cables. The g[illegible] the colliery. At the same time it is essential that the cable should not be less than a minimum length in order [illegible] wise break down t[illegible]

[illegible]

referred to on page 327 is necessary, otherwise there is a danger of birds operating the Merz-Hunter gear.

(b) *Distribution underground.*—In reply to Mr. Jones the whole of the cables in underground roadways are suspended.

In reply to Mr. Cramp, the stresses to which cables are subjected in underground roads are in no way comparable with those in engine or pump rooms. Rooms of this character are comparatively free from settlement and falls to which the cables in the underground roads are exposed, hence the necessity for suspension in roadways.

(c) *Earthing connections.* Professor Thornton gives as his experience that "dead" short-circuits between the cores of a multicore cable, lasting during "the second" before the trip gear operates, produce no external effects on the armouring except the blow causing the fault. I think this experience must have been gained with undertakings operating with comparatively small generating plant, as it is contrary to my experience with short-circuits lasting for a far shorter period than that given by Professor Thornton. The only cases in which I am aware of sheathing being unmarked when the cables are connected to a large system is when a special system of protection, such as the Merz-Hunter, is used in combination with effective armouring and earth-plates.

Mr. Selvey asks, having in view the difficulty of earthing, whether iron-clad switchgear should be entirely accessible. Under normal conditions with the whole of the system bonded the risk is small, but in event of the earthed sheathing not being continuous, risk arises. The remedy is to see that the conductivity of the earth-plate is low, and that the earth-return conductor is made an integral part of the cable.

Mr. Anderson wishes to know my experience of the continuity of metallic sheathings and bonds. Owing to the difficulty of maintaining good conductivity of the sheathings at joints, I advocate on page 398 of the paper the use, in addition to the sheathings, of either a copper sheath under the lead or an additional conductor forming an integral part of the cable to secure an efficient connection to the main earth.

Dr. Worrall raises the question whether the armouring of the high-tension pit cable is a sufficient connection between the armouring of the low-tension system in the pit and the earth-plate on the surface. Assuming that the neutral point of the low-tension system is effectively earthed, the armouring of the high-tension cable should be sufficient, but owing to the difficulty of securing an effective earth at the pit bottom, it is necessary, except in exceptional cases, to run a substantial conductor of low resistance between the pit bottom and the earthing system on the surface, the armouring of the high-tension cable being insufficient to ensure protection. Dr. Worrall's statement is of interest; he admits that while the average conductivity of the earth-returns was within the limits required by the Regulations, in one case total discontinuity was found. This points to the desirability of the earth-return being an integral part of the cable, as recommended in the paper.

(d) *Earth-plates.*—I am glad to see that Professor Thornton agrees that more efficient earth-plates are required than those recommended in the General Regulations to prevent rise of pressure on cable sheathings. On page 401 I draw attention to the fact that the effectiveness Mr. Spa of the earth-plate is due rather to the size of coke bed than to the dimensions of the metallic plate itself. The earth-plate described by Professor Thornton should be effective on the surface, but I am doubtful whether it would produce an effective earth "in-bye" until further tests have been made as to the conductivity of the strata. Further, owing to the crush and movement of the workings, it is difficult to maintain any effective coke-bed underground.

Mr. Hunter states that with normal earth-plates of the type recommended by the General Regulations Fig. 11 suggests that an earth fault of 500 amperes might result in a potential difference of 230 volts between the earth-plate and earth. Taking the lowest resistance obtained from the earth-plate recommended in the General Regulations, connected two in parallel, the resistance to earth would be 1 ohm, and Fig. 11 therefore suggests that the pressure to earth at the earth-plate may be 500 volts. The actual pressure on the cable sheathing depends largely on the condition of the sheathing, and I agree with Mr. Hunter that if the sheathing is in good order and of very low resistance only a fraction of the current will pass through the earth-plate. From accidents which have occurred it is clear that the sheathing of cables becomes charged, and a low resistance both of sheathing and earth-plates is therefore necessary. Owing to the difficulty of maintaining the joints in sheathing, I recommend that the earth-return conductor should be an integral part of the cable. In the special case mentioned by Mr. Hunter of the breakage of the earth connection at a motor, I agree that the resistance to earth at the motor is more important than the resistance to earth at the earth-plate, but this is an exceptional condition, and under average circumstances a much larger margin of safety will be obtained by decreasing the resistance to earth at the main earth-plates than is provided by the present Regulations. Where practicable, it is of course advantageous to have distributed earth-plates which will further reduce the class of risk to which Mr. Hunter refers, but it is difficult to make an effective earth-connection underground. In connection with Fig. 10, I agree with Mr. Hunter that it is desirable that the connections to deeply buried earth-plates should be made by insulated conductors.

I agree with Mr. Beard's remarks as to the difficulty of providing a permanent and effective connection to earth-plates. The most suitable method is to use a tramway bond expanded into a cast-iron plate with a boss of ample section. While the form of earth-plate suggested by Mr. Beard for a sub-station earth would result in securing an effective earth connection, a coke-bed foundation would not be sufficiently strong to carry the weight of normal sub-station buildings.

The tests on Mr. Anderson's earth-plate are of interest and show the difficulty of getting a low-resistance earth even where special pains are taken, the resistance in this case being some $1\frac{1}{2}$ ohms; I suggest that a similar result could have been obtained with one of the cast-iron pipes had the coke bed been of similar area. No particulars are given as to the characteristics of the surrounding soil in which this earth-plate is buried. In further applications of this type of earth connection, the coke bed should be placed well below the ground to reduce the potential gradient on the surface.

[illegible]

[illegible] insulated neutrals, and 3 for those with earthed neutrals.

[illegible] and extra-high-pressure generators is earthed through [illegible] Duffryn undertaking, although I use it in connection with [illegible]

[illegible] tension systems used for mining work should be worked with an insulated neutral. While it is possible to secure [illegible] city and reliability of the system of protection when the neutral is earthed. In view of the essential importance of safety, I am in favour of the simpler system which, while taking advantage of automatic devices, eliminates these devices as far as possible.

Mr. Baxter advocates working with an insulated neutral [illegible]

[illegible]

[illegible] Mr. R. Nelson, H.M. [illegible]

[illegible] pressure three-phase system, two on medium-pressure con- [illegible]

[illegible] statement that nearly all fatal accidents due to electricity below ground have occurred, not on unearthed systems, but on earthed systems where there has been a too high [illegible] than is suggested by Mr. Anderson.

[illegible]

[illegible] an overload attachment with a high setting on the generators, otherwise in the event of a breakdown on the [illegible]

Mr. Sparks. mission lines and power station. The size of the undertaking has not yet warranted the running of such apparatus at the individual collieries, and owing to the present impracticability of applying power-factor correctors to individual motors, it is proposed, as stated in the paper, to apply power-factor correctors to some of the larger motors. I am unable to follow the statement as to the probable saving of many thousand pounds in capital expenditure through the use of a synchronous condenser, the only point of saving up to the present would be in the generators, as the transmission lines would not have been reduced in section. As will be seen on reference to the paper, the number of transformers in use is small. When any difficulty is found in maintaining pressure regulation through overloading the transmission lines, their capacity will be increased by adding power-factor correctors as indicated in the paper.

In reply to Mr. Cramp, improvement of the power factor through the use of a Tirrill regulator is due to the maintenance of a steadier pressure. For instance, when switching on an alternating-current winder taking say 800 k.v.a., the pressure would fall, resulting in a lower power factor. By using a Tirrill regulator the pressure is maintained at a more constant figure, which has the effect of materially improving the average power factor.

Mr. Hunt suggests that some of the larger low-speed motors should be fitted with exciters. An analysis of the 45,000 horse-power of motors now in use shows that few low-speed motors are available, and that the majority of these are of variable speed. In consequence, the scope for correcting the power factor in this way is more limited than is generally recognized. It is interesting to note that induction motors must be specially designed in order to get the best results with power-factor correctors, owing to the rotor teeth being of insufficient area to carry the increased flux when working with leading, instead of lagging power factor. I agree that the simplest method of power-factor correction is to use a synchronous motor with a continuous-current exciter, but unless the transmission is to one main point, it is impossible to use power-factor correctors of this type, owing to the cost (due to the number of units involved) and the difficulty of supervision.

Mr. Foster asks how often the oil-insulated transformers are opened out for inspection and the oil changed. The usual practice is to change the oil when the working temperature exceeds the normal with transformers operating at rated duty.

Individual Drives.

Winders.—In reply to Mr. Leggatt, I pointed out during the discussion before the Institution* that at the time the electrification of the Britannia Colliery was under consideration it had not been found possible to interconnect the whole of the generating stations of the Powell Duffryn Company, consequently the large unbalanced load at the Britannia Colliery required the use of Ilgner flywheels. Since the paper was written the 20,000-volt interconnector between the Aberdare and Rhymney Valley stations has been put in hand. This will interconnect stations having 15,000 kilowatts of plant running normally to meet a load of some 11,500 kilowatts. With these altered conditions the third converter set for the Britannia Colliery just ordered is an ordinary Ward Leonard set without a flywheel. Mr. Sparks.

* See page 430.

Mr. Shuttleworth refers to the inefficiency of the control of the converter sets by slip regulators on the induction motors. When this plant was under consideration in 1910, enquiries were made as to the possibility of improving the power factor and returning part of the power wasted in resistance to the system, but no proposals could be put forward at that time for dealing with this point. I am much interested in Mr. Shuttleworth's statement that the recent development will allow the return of the bulk of the energy now wasted. With reference to his suggestion that a large annual saving is available on the basis of energy costing 1d. per unit, no large power applications such as those instanced in the paper would have been possible if the cost of energy had approximated to this figure. I am of the opinion that the main advantage of the development proposed is in the improvement of the power factor, and its success is dependent on its reliability. The question of the additional expense of maintaining the existing slip-ring regulators is a minor matter, and in any event is far less than the cost of maintaining a commutator motor.

Mr. Brown suggests that the winders are fitted with double commutators. Reference to Fig. 21 shows that this is not the case. Each winder is driven by two motors, each rated for a maximum output of 2,150 horse-power and having a single commutator. Having regard to the size of the winder, it is of great practical advantage to drive from either end, and although the failure of a motor is remote, it is important to be able to wind at reduced speed should one motor be disabled. With regard to brakes, having regard to reliability it was decided that two braking systems must be available. As to the time of braking, this is dependent upon the construction of the brakes, it being possible to slow up in less time if the wood brake blocks are allowed to fire. Having regard to the duty to be performed, sluggishness of the slip-ring regulator is not a disadvantage. The amount of power required to operate the same is small.

Pumps.—In reply to Mr. Cramp, constant-power pumps have not been used up to now. This has been no disadvantage as there has been no shortness of power.

Ventilation.—In reply to Mr. Cramp, in the absence of air filters and in spite of every care being taken an accumulation of coal dust will be found in underground motors after these have been run any long period. To minimize the delay and inconvenience due to shutting-down plant for cleaning, it has been found beneficial to fit air filters to the larger-powered pump motors, which results in prolonging the life of such motors. The comparatively high air pressure is due to the filters having been added to the original equipment. It is possible, with ample space for ducts and filter, and with a motor designed for forced ventilation, to work surface plants with the reduced air pressure of from 1 to $1\frac{1}{2}$ inches.

Compressors.—Mr. Jones suggests that I advocate the use of continuous-current motors used "in-bye" for compressor drives. This is incorrect; I only advocate the use of continuous-current motors where variable speed is required for driving large compressors on the surface until suitable alternating-current control is developed. I entirely agree in regard to the desirability of introducing

[illegible]

brake

[illegible]

of this size are developed, together with the prospect of the reduced weight of cell with improved vacuum lamps.

[illegible] indicator as an additional attachment to the miners [illegible] that the indicator shall draw attention to the presence of [illegible]

[illegible] bulb maintenance is due to the difference in pressure given [illegible]

[illegible] insulated wires, I advocate the u[illegible] of substantial section, run on insula[illegible] switches the risk is a minimum.

[illegible] not exceeding 25 volts o[illegible] owner's behalf. I had no hesitation in a[illegible] safety in future, I am indebted to [illegible]

Mr. Sparks. I still feel it preferable to use such a switch rather than to allow signalling by bridging the bare signalling wires. With regard to the factor of safety at Senghenydd, Professor Thornton's inference as to the absence of a factor of safety is not justified. The safe current suggested by Dr. Wheeler was tested under different conditions from those prevailing in the pit, and I think, in view of the importance of the matter, that additional Government tests should be carried out under conditions that could not admit of question before any positive statement can be made. When such tests are made, the safety limits should no longer be defined in volts and amperes. With regard to the future, I do not advocate repeating the Senghenydd conditions, and I have defined the conditions which I consider desirable on page 423, sub-headings (1) to (5).

Dr. Garrard refers to an electric-bell relay which eliminates sparking altogether. This is one of the systems advocated on page 424 of the paper.

Dr. Morris confirms the opinion stated on page 424 of the paper as to the safety of the alternating-current system when applied to electric bell signalling. Mr. Sparks.

Professor Marchant advocates the use of a non-inductive resistance for shunting the magnet coils of the bell. This is a material improvement on the safety arrangement (2) suggested on page 423 of the paper. At the same time I am of the opinion that it is advisable to minimize the risk of "break-flash" on the wires by the use of an enclosed switch, as recommended in sub-heading (5) of the paper.

In reply to Mr. Clothier, Fig. 32 has been inserted in the paper and shows the battery distributed over the line, thus meeting the point raised *re* my statement (3) on page 423. The information as to the characteristics of the relay for operating bell circuits is of interest, and, if this is satisfactorily developed, the alternative (B) mentioned on page 424 of the paper should in most cases take the place of the arrangement suggested under (A).

DISCUSSION ON

"ELECTRIC COOKING."*

YORKSHIRE LOCAL SECTION, 10 MARCH, 1915.

Mr. Campion. Mr. R. H. CAMPION: On the assumption that the cooking load can be supplied at ½d. per unit there is certainly a good case for the electric heating of water at ¼d. per unit, but I think that central-station engineers have already taken a very liberal and broad view in offering such rates as ½d. per unit. In fact it has been said for some time that central-station engineers have done their share and that manufacturers ought to do more; the contractors also ought to help to push the apparatus. I think that for a load factor of 10 per cent (I propose for the present to leave out of consideration the question of diversity) the rates quoted by most supply authorities are very liberal. I was very interested in the author's figures for the average consumption of electric energy per month, because at Dewsbury we have now adopted the assessment tariff—15 per cent of the rateable value and ¾d. per unit—and I find that those consumers who have cooking apparatus use about 250 units a month. That is a very fair consumption with a family of four or five, and it is with the condition that the consumer who accepts this assessment tariff must, according to his rateable value, install a certain amount of heating or cooking apparatus. I copied the Manchester tariff in regard to the amount of heating and cooking apparatus which must be installed, and I find that in nine—in fact almost eleven—cases out of twelve the consumer installs heating apparatus only. Now from our point of view—and the author mentioned this point—heating apparatus provides no load for the central station in the summer months. Those consumers who have got heating apparatus are only taking 10 units a month in the summer as against 250 units a month in the case of those who have cooking apparatus. I have installed a water-heating apparatus for office purposes and I find that on the average it only requires 9 units a week. The question of the outlay necessary when cooking apparatus is installed is a very important point. We have at Dewsbury some fairly wealthy men, and I find that they will not install apparatus even at half the price that the author has paid. They say they will hire the apparatus, but will not spend £12 10s. on buying it. It looks as if engineers are much broader-minded than some wealthy manufacturers. As the author says, when the cooking apparatus has been installed there is the hot-water problem. If the coke-fired boiler is not adopted, then of course the consumer has been served in only half the way that he should have been and he will certainly be lost to the undertaking. This question of water heating is a very difficult problem, and if it is to be at only ¼d. a unit the margin of profit for the supply authority will be very small in these times when coal is so expensive. I wish to endorse what the author has said in regard to the earthing of apparatus. As regards the use of a thermometer, I have always wondered how cooks manage without thermometers and how they are able to guess the temperature by placing their hands inside the oven. With regard to the bending tests, I was rather surprised when I looked at No. 17 where a steel wire is used. We have all found, and I think most of the cable manufacturers are now coming round to that view, that a steel wire inserted in a flexible cable increases the mechanical strength con- Mr. Campion.

* Paper by Mr. W. R. Cooper (see page 473).

say not less than seven or eight shillings per week. They

place electric cooking on the same

the point of view of the consumer. That is the right point of view, I think, because after all it is generally not the

and cost of current, as compared with coal

load factor, though whether the a

latter would wish to carry, for

however, upon the installation of

Mr. Wright. meal, and I think we can take that as a very creditable performance. Personally I am rather sceptical as to the claims made by some manufacturers of electric cooking apparatus as to the greater efficiency to be obtained by electric cooking, as against gas or coal. I do not think there can be very much in it and, as the author mentions, it is altogether a question of the correct regulation of temperature. There are many other advantages of electric cooking mentioned in the paper, such as cleanliness, regulation of temperature, reduction of waste, which are bound to appeal strongly in its favour, but I think the difficulty at present is the great difference in first cost of the apparatus as compared with gas or coal cooking. As soon as these become comparable, electric cooking will come much more extensively into domestic use and a reduction of the cost of current and maintenance will automatically follow.

Mr. Wallis. Mr. E. C. WALLIS: I feel sure that electric cooking is one of the coming things. The people who cook are very conservative; they were at first very unwilling to adopt gas cooking, and at present are not anxious to try electric cooking, but this feeling will be gradually overcome. Great progress has already been made, but I consider that the manufacturers of the apparatus have a great deal yet to learn. I sometimes think that if those who make things had to use them, they would gather some very valuable hints. In the construction of electric ovens, for instance, consideration must be shown for the people who have to use them. The slides which pull out are not always so arranged that when they pull out they will be self-supporting. Electric ovens are made where such slides only rest on ledges. That is not sufficient. Ledges are needed above the slides as well as underneath. It is by attention to such details that perfection is attained. Then again, as the author has said, the position of the switches is most important. If the side of the oven on which the switches are fixed has to be put very near to a wall the cook cannot see the switches which she is using, so that it is very difficult for her to control them properly. Years ago we used to have to complain of the connections between the sockets on flexible cords and the plugs on apparatus. They used to get almost red hot if people did not take the trouble to put them in carefully. It occurs to me, as it has occurred to the author, that electric apparatus for cooking or heating needs frequent attention, on the principle of the old adage that "A stitch in time saves nine."

Mr. Lang. Mr. W. LANG: I propose to confine my remarks to the question of flexible wires. I am afraid that the author has not gone into the tests with much experience or inside knowledge as to what is required for different types of flexible wires, or even what is likely to take place by subjecting different makes of wires to similar tests; and he reaches really no conclusions at all. In connection with the tests he says, "ordinary flexible wires vary very much in their mechanical properties and it is not necessary to depart from the ordinary type to get excellent results." I think, however, that his own tests show that there are very great differences between the various types, and perhaps an intelligent investigation of the different kinds might disclose why one is weak or why another is stronger or gives a better apparent result. It will be noticed that some of the wires tested were insulated with a double covering of pure rubber and others with pure rubber and Mr. Lang. vulcanized rubber. Apparently the author has not differentiated between the two in regard to their value for different classes of work. Since pure-rubber insulation is quite useless in damp places or in positions where a considerable amount of heat is likely to affect the rubber, the author's tests on pure-rubber-insulated flexible wires for this particular class of work—that is, for use with hot apparatus—are in my opinion of no use whatever. After it has been used for a short time with a hot utensil the flexible wire will alter radically; though I do not think the copper conductors would be materially affected, yet the insulation would deteriorate so very much that its usefulness would be quite destroyed. At any rate the results of the author's tests bear no relation at all to the value of the insulation from the point of view of actual working conditions. The test on wire No. 5 he states is unsatisfactory, yet judging by the figures for the number of complete bends the result is just what I should expect. The insulation being of pure rubber is at an advantage for such a test. That is to say, these very small 40 S.W.G. wires being insulated with pure rubber are not affected by the heat as are flexible wires insulated by vulcanized rubber. The actual process of manufacture of vulcanized-rubber flexible conductors so heats the very small wires that they become considerably shorter when they are put into use. Therefore, if a vulcanized-rubber wire is tested and one expected to obtain the same result as with a flexible cable of the same size insulated with pure rubber, the results will differ for the reason mentioned above. The test on No. 6, which the author on page 479 mentions as being an "Association flexible wire," is of course what we should naturally expect. I think that it is really a very satisfactory test indeed for a pure-rubber-insulated wire, and it gives a very good breaking stress. In spite of that, however, it is not the flexible conductor that I should recommend anyone to use with heating apparatus. The wires should be of 38 S.W.G. Those special flexible conductors made with steel strand are inherently unsuitable in my opinion. I do not think any composite wire for this class of work would be satisfactory. There is the difference between the bending of steel wire and of copper wire, and unless the actual stress is identical in the two cases there will be comparatively so much friction between the copper and steel strands that a very short life will result. No composite flexible wires have been successful except those made for army purposes, such as field telegraph wires, which with few exceptions are made up entirely, or almost entirely, of steel wires and are so constructed as to be strong enough to withstand bodies falling upon them or men tripping over them. I know of no wires of this nature which are really of any value whatever. Wire armouring is a very poor method of protecting small flexible cables. The weakness lies in trying to strengthen by metal wires a wire which has to stand continual handling. This in practice is found to defeat its own purpose. There are other and better methods of protection if this is necessary, and generally speaking the principal object should be lightness in weight as well as flexibility in the material which has to act as the extra protective covering.

Mr. Collinson. Mr. P. COLLINSON: As a contractor I am naturally interested in this question of electric cooking. The

[illegible] cookers, there is little to be done in competition with gas [illegible] made in thousands it will perl[illegible]

[illegible] let alone universal, on anything like the basis of these costs. I think the author's remarks on earthing are very much to the point. There is no doubt that in a good [illegible] done. Like the previous speaker, I think that electric cooking apparatus cannot be handled efficiently at the present moment by the contractor, and as those who are [illegible] advance the use of electric cooking, or at any rate tend to improve the apparatus, more efficiently than any other. I think it was Mr. Seabrook who during a discussion on electric vehicles remarked that after all it was the supply [illegible]

[illegible] should like to ask him whether h[illegible] tractor he does not know what he ha[illegible] until he gets his account, and then he [illegible] it is necessary to use very much [illegible] quently larger conduits. [illegible] faction. There was a little trouble with it to [illegible] in connection with the failures of the [illegible] pointed out very clearly and very [illegible]

Mr. Moss. replace faulty elements free, inasmuch as they gain more in the end than the contractor does as the middle-man. My electric lighting, cooking, etc., costs on the rateable-value basis, which I very much appreciate, something like £4 10s. per half year and I am very well satisfied.

Mr. Cooper. Mr. W. R. COOPER (*in reply*): In regard to most of the points raised in this discussion I must refer speakers to my remarks in reply to the discussions at London, Birmingham, and elsewhere, more particularly as to the class of consumer to which my results apply, the size and cost of apparatus, etc. The remarks of Mr. Campion on maintenance strongly support the views expressed in the paper. It is clear that the figures which he gives are uncommercial. In time, no doubt, the cost of maintenance will become quite small, but meanwhile the cost above a certain figure should, in my opinion, be borne by the manufacturer if we are to make proper progress. In this I agree with Mr. Moss. I doubt if these small repairs can be carried out on a suitable basis by a contractor, because contractors must see some profit on their work, as Mr. Moss suggests. The electricity undertaking, on the other hand, sees a profit from the supply of energy, and can therefore afford to carry out these repairs at cost price.

Referring to the remarks of Mr. Wright, a house of £25–£30 rental would not need nearly such a large cooker as the case to which I have referred. Also it is cheaper to put plant into a house when building than subsequently. I think that for such a case a cooker and coke boiler could be installed for well under £20; much depends, of course, upon the selection. Mr. Cooper.

I am interested in the remarks of Mr. Lang. The troubles that I have experienced have not been due to heating of the flexible wires, because they have been attached by porcelain connectors. I purposely did not draw any very definite conclusions from my tests, as I felt that a proper consideration of the results required a knowledge of cable-making, which I do not possess; but there are other engineers who I hope may be able to draw useful conclusions. I do not agree that armouring is useless, as the results obtained with sample No. 10 are excellent, but this sample belongs rather to the larger class of flexible cables.

In reply to Mr. Collinson, I do not think he need invest nearly so much as £20 per cooker for the case which he considers. Hiring out, however, is unquestionably a difficult proposition for a contractor and can be undertaken far better by the supply authority. As to the cost of cookers, this must depend largely upon the turnover of the manufacturer. There have been heavy experimental expenses which the manufacturer naturally wishes to recover, but as soon as the turnover can be large, with a standard design, the establishment charges per cooker must fall, and the price can then be reduced.

In reply to Mr. Moss, I would not suggest the earthing of all portable apparatus in a house. This is, in my opinion, unnecessary. But there are positions, such as bathrooms, where earthing should be adopted, as well as in the kitchen.

BIRMINGHAM LOCAL SECTION, 17 MARCH, 1915.

Mr. Grogan. Mr. F. S. GROGAN: In the adverse criticism which I have to make on this paper I wish to make my position quite clear. I do not speak from the point of view of one manufacturer against other types of electric cookers, but as representing all those men, not only manufacturers but station engineers, who have devoted some years to the advancement of the electric cooking business. I maintain that the figures published are those of a special case which is not at all representative of the general results obtained. [The remainder of Mr. Grogan's remarks were substantially the same as those which will be found under his name on page 487.]

Mr. Smith. Mr. T. SMITH: I consider that the author has taken a very unfair, I might say artificial case, and it looks almost as if he allowed himself to be misled into believing that the results he has obtained are representative of the results obtained with electric cooking generally. Were it not for his position and interest in the question of electricity supply, I would say that the matter had been handled by a competitor whose endeavours were confined to proving that electric cooking was a complete failure. We have for instance a consumer purchasing a £23 outfit, when apparently the joints to be cooked are only about 5 lb. in weight. He must be aware that he can purchase several outfits which would have met his requirements for less than half this amount; to mention two only, I would refer him to the "Carron" and the "Jackson." Also utensils to the value of £2 5s. 0d. are mentioned, an absurd figure even for good aluminium utensils; further, a charge of £9 4s. 5d. for wiring, a figure which ought to be sufficient to include a service off the street distributor, and the wiring to a cooker in any ordinary house. The information given as to the loss of weight of meat in the process of cooking is certainly in favour of the electric cooker, although the author wishes us to believe that it is not worth considering. The surprising part is, with such small joints and the heavy consumption of energy, that any saving at all is shown. The tests are not altogether fair, as they have been taken with ribs of beef only; it would be interesting to know why mutton, veal, and pork have been excluded. Had this been done the results would have shown more in favour of electric cooking. I think we have reasons to be proud of even a 14½ per cent loss, but I think a good cook can easily make this 10 per cent on all-round cooking. The method of regulating the heat of the oven is peculiar, and I imagine that once the new toy period is over, the cook will give up "fiddling" with the low heat and will settle down to a more rational method. As to the thermometer, I think a cheap portable one to hang inside the oven is useful, just to lend to the scientifically inclined consumer. I say cheap because it soon gets broken, and indeed the sooner the better. The question of plugs is important, but the trouble will be overcome when a reliable interlocked switch and plug is brought out. I certainly think that the design shown in Fig. 2 would aggravate the trouble which it is supposed to remedy. I consider the suggestion of using special flexible cords to be a good one, and no doubt if we had suitable connectors the "cab-tyre" type is the best at present obtainable. The result of the tests on Mr. Smith.

[illegible] regards tariffs, I note that [illegible] realized by the author, and the same remark applies to the manufacturers. The part which the manufacturer has to [illegible] repair. The effect of diversity factor is a most difficult one [illegible] point of view. To justify my view that the paper is a mischievous one, I may say that I consider the author has ignored the good points of electric cooking, but has pointed out and exaggerated all its defects. Also, not being satisfied with the defects which become apparent to the [illegible] apparatus. In my experience nothing more harmful to electric cooking than this paper has been put forward, and I fully expect to have to meet quotations from it for some years to come. The author will be quoted as a [illegible]

[illegible] function of the wind means that the [illegible] They were persuaded to replace the old ovens by [illegible] electric oven and its easily [illegible] way they have refunded the extra profit to the c[illegible] deal with the consumer. A number of years ago I intro-[illegible]

appreciate his point of view and understand his requirements.

Mr. J. H. C. BROOKING: Information that I have received from central-station engineers all over the country shows that flexible cables appear to be the weakest point in connection with portable heating appliances. Therefore, although the tests of "bendability" described in the paper hardly seem necessary in connection with electric cookers, which are generally permanent fixtures, they will possibly be of interest to some engineers. There is, however, more necessity, for the purposes of the present paper, to deal with other causes of failure in ordinary cables used in connection with cookers, etc., such as kinking and abrasion, and more particularly in regard to immersion in steam, moisture, and grease due to cooking utensils boiling over. No reference is made in the paper to troubles from these causes, and most of the tests described are upon cables with fibrous protection such as cotton, silk, worsted, twine, and cord, all of which absorb moisture and fray. Some of the flexible wires were armoured with brass and tinned steel wire, which would rapidly corrode. In regard to the special wiring required for extensions to lighting, instead of the old-fashioned, very expensive, and condensation-threatened screwed-tubing practice, many engineers now recommend the running of a protected cable for this work.

Mr. G. S. CATTELL: From the paper it would appear that to cook for nine people the author used a cooker which was probably capable of cooking for a larger number, possibly fifteen. On this account the current consumption in kilowatt-hours per person per day comes out much higher than has been found to be the average amount required. The initial cost of the cooker in question, together with utensils and wiring, seems altogether too heavy. It would surely be possible to provide a complete equipment to do all the work required at a cost of less than half the amount shown. Referring to the question of switches, a main double-pole switch is very desirable. A single pilot light is really all that is necessary, and I agree entirely with the author on this point. Separate pilot lamps should be regarded as luxuries. They are quite good when the apparatus is under the supervision of an engineer, but failure of a single lamp, whether in series with, or in parallel with the heating elements, is apt to cause confusion. Switches for the heating elements are much better if double-pole, and this particularly applies to griller switches if the heating element is exposed. The author favours the use of a thermometer, but I cannot think that this addition is of real value. A thermometer may give some indication of the time when the oven is hot enough to commence cooking, but fails entirely if it is desired to assist the operator when requiring to change the temperature of the oven. An intelligent cook will rapidly become sufficiently well acquainted with what the cooker will do, so that a thermometer in any case is not of lasting value. To know exactly what is the temperature of the oven may help considerably when the question of saving in weight of meat is considered, but this point is possibly made too much of. The saving with electric cooking is real enough, but the advantages over other forms are so numerous that surely most stress should be laid on those which most appeal to the feminine mind. The question of saving in meat becomes much more important when cooking is done on a large scale as in restaurants. The author deals in detail with connectors for portable apparatus, and it is evident that the arrangement shown in Fig. 2 could be improved. The ideal connector is obviously one enclosed in an earthed metallic sheath which comes in metallic contact with the portable appliance before the element becomes alive. The whole question of earthing is one which cannot be given too much attention, and in this direction I would endorse all of the author's remarks. From the author's tests on flexible wires it is obvious that the circular twin is preferable to the twisted twin type, and experience proves that it is less likely to become damaged as a result of kinks. Further, there is no difficulty in obtaining circular twin flexible wire that is sufficiently flexible for all ordinary use. So far as the general design of cookers is concerned, manufacturers at present are working under a great disadvantage, inasmuch as the opinions of the engineers who are the principal purchasers differ rather widely, thus causing considerable variation in specifications. This means that any cooker which is made a standard has often to be modified in order to secure a fair share of orders. If, therefore, domestic cookers can be reduced to fewer types as a result of agreement between engineers as to what is best, not only shall we arrive at something more nearly approaching the ideal, but we shall also be able to manufacture under such conditions that the price to the ultimate user can be materially reduced.

Mr. C. O. SILVERS (*communicated*): I presume that the purpose of this paper is to invoke a discussion which will be a means of throwing some light on the consumer's point of view. During the last 15 months I have had an opportunity of watching very closely an electric cooking and heating installation in an hotel in the Midlands, which for many years has had a reputation for good cooking. Electricity replaced gas in this case with the following results, which I hope may be found of interest to members. Up to the end of 1913 electricity for lighting was paid for at the rate of 2½d. per unit (flat rate). The price of gas is 2s. 6d. per 1,000 cubic feet. With the installation of electric cooking the tariff was re-adjusted as follows :—0·5d. per unit used, and a fixed charge based upon £8 per kilowatt of demand, with a diversity-factor for occasional lights, heating, and cooking. The apparatus consists of one double oven of the "bright" unlagged type, taking 3,200 watts, three 800-watt hot-plates, one 3,000-watt double grill, one 2,000-watt fish fryer, four 2,000-watt electric fires, and 11 light points taking 350 watts, making a total of 18,950 watts. This apparatus replaced gas, but the following new plant was added :—One hot cupboard and carving table (3,000 watts), two 800-watt hot-water urns, one 2,000-watt electric fire, and 14 light points (requiring altogether 450 watts), *i.e.* an additional 7,050 watts. The cost of electricity, coal, and gas for the two years preceding the cooking and heating installation and for the first year of electric cooking and heating was as follows :—

	1912. £	s.	d.	1913. £	s.	d.	1914. £	s.	d.
Coal	35	10	2	26	16	1	35	5	0
Gas	47	12	2	53	0	10	13	0	2
Electricity	27	15	2	32	0	2	66	13	3
Total ...	110	17	6	111	17	1	114	18	5

[illegible]

a commercial standpoint, for not only do the costs com- [illegible]

[illegible] prevent a varying amount of loss in weight, especially in small joints. I should particularly like to point out that the only capital expenditure that has been necessary for these results is that to cover the wiring and [illegible]

[illegible] standardization of socket connections for cooking ap- [illegible] present moment two movements are in progress. One [illegible] me that these two requirements are incompatible unless a uniform standard interlocked switch-plug is manufactured [illegible]

[illegible] so easy.

[illegible] (as Mr. Smith and Mr. Cattell appear [illegible]

[illegible] plate is reduced unduly, it becomes difficult for the cook to [illegible] instance the size of the top plate of the el[illegible] for other classes of consumers.

With regard to utensils, Mr. Smith evidently uses the ordinary variety. The price given in the paper is for iron [illegible]

[illegible]

Mr. Cooper. energy. The tests were restricted to a single type of joint so as to have the results comparable.

With regard to the tests on flexible wires, nothing was removed from the U-shaped part of a sample, including the portions under the clamps; of course, beyond the clamps any cutting away was immaterial to the test.

As to the cost of wiring, as mentioned elsewhere, this was carried out by the electricity supply undertaking. Being somewhat pressed by other affairs I adopted this method of obtaining the wiring, and was assured that the charge was not unduly high. Presumably if I pay too much when I become a lay consumer, other lay consumers are liable to suffer in the same way. My view is that an electricity undertaking should not carry out work of this kind—certainly not if they wish to see a profit on it. The average contractor is better equipped for such work and can do it more cheaply.

In reply to Mr. Hollis, a pyrometer would no doubt be an advantage, but I think the cost would be too great. Personally, I have not found any difficulty from the breaking of the thermometer on the oven door. It might, however, be better to have the thermometer fitted above the door, in the body of the oven, and I believe this is done in some cookers, though, possibly, from the point of view of indicating the true temperature the lower position is preferable. I quite agree that the case for electric cooking for wholesale work is very different from the case for domestic working, and there are some electrical advantages which become of much greater importance in the former.

Mr. Cooper. I agree with Mr. Brooking that tests on kinking, abrasion, and absorption are important in regard to flexible wires under certain conditions; but the trouble I experienced more particularly was due to bending, and consequently I made tests on this particular point. With the usual smaller portable apparatus absorption is not important. On the other hand, abrasion is an important matter in the case of radiators.

Referring to the remarks of Mr. Cattell, I fear that double-pole switches for individual circuits would lead to considerable expense, and I do not think they are necessary, provided, of course, that a main double-pole switch is fixed conveniently near the cooker. I do not agree with the view that a thermometer fails in assisting the cook to change the temperature of the oven, provided it is so made as not to have a considerable time lag.

I am interested in the results given by Mr. Silvers, and I think there is no doubt that electric cooking will have a good future in restaurants and hotels. In regard to earthing, I do not consider it necessary to earth all portable apparatus, and there would be a good deal of difficulty in doing so; but in special positions, such as bathrooms, apparatus should certainly be earthed.

Referring to the remarks of Dr. Garrard, no doubt interlocking of plugs and switches is desirable in some respects, but it must add to the expense. It seems on the face of it rather a needless complication. Moreover, if a rotary switch is used for different heats there would seem to be some difficulty in arranging matters with a 4-pin plug.

MANCHESTER LOCAL SECTION, 23 MARCH, 1915.

Mr. Welbourn. Mr. B. WELBOURN: In my own household electric cooking has been used for nearly three years, so that I have some experience on which to base my remarks. In the first place I wish to emphasize my agreement with a great many of the recommendations that the author makes. With regard to consumption, we find that this is something like $1\frac{1}{2}$ kilowatt-hours per person per day. My own observations, which were made when the cooker was first installed, confirm the author's results (set out in Table 3) in regard to the loss in cooking by electricity at "normal temperature." Another point to which I should like to call attention is in reference to the statistics which the author gives for the cost on page 474. It has often been stated that half the coal consumed in a house goes in the kitchen grate, but I have never seen this assertion examined so carefully before. Here there is absolute confirmation. In one case the coal cost £13 10s., and after electric cooking had been substituted the cost was reduced to £6 13s. 6d., *i.e.* halved. With regard to the arrangement of the gear, I agree entirely that the controlling switches ought to be mounted on the wall. If the supply is taken from the outers of a 3-wire single-phase system the main switch ought to be a double-pole switch and not a single-pole switch, so that the apparatus can be entirely isolated when the main switch is opened. I also find from experience that a pilot lamp is a very useful accessory. With regard to earthing, I am glad to find that the author has taken the question up so strongly. My own view is that not only electric cooking apparatus but every power circuit in a house, whether for radiators or for any other purpose, ought to be so arranged that the apparatus itself can be earthed, and I would suggest that the Home Office Mining Rules might be remodelled to suit domestic conditions. Another accessory on which I want to say a few words is that of flexible wires for connecting up the apparatus. I have been using flexible wires of one kind or another for seven or eight years, and I suppose that during this period I have experienced all the troubles that the author has evidently suffered so as to make it worth his while to conduct this exhaustive series of experiments. The result of my own trouble has been that I have entirely discarded rubber-insulated flexible wires, and that I am now using, with satisfactory results, flexible wires insulated with asbestos only and then covered with strong thread. Since I adopted them, 18 months ago, I have not had any further trouble on this score. They stand heat and more ill-usage than rubber-insulated flexible wires. I do not know whether they comply with any Home Office Regulations that there may be relating to them, but that is what I am doing and it is entirely satisfactory in practice. In regard to the cost of cooking by electricity, my experience does not tally with that of the author. For the first two years I kept accurate accounts of the heating bill of the house and the total difference between the electric cooking year and a coal year was 25s. The charge for energy was 1d. per unit on a flat rate, with $2\frac{1}{2}$ per cent discount, and with a family of eight it only made a difference of 25s. The price of coal in my district (*i.e.* South Lancashire) averages 17s. 6d. per ton. It seems to me that the apparatus which the author has installed was probably a

[illegible] the properly installed apparatus the [illegible]

[illegible] years we have had probably four hot-plates put out of use, but the makers were very good and replaced [illegible]

[illegible] take my current, I pay a flat rate and I suffer from the [illegible] the bill is to be at the end of the quarter. Ever since [illegible] apparent my thoughts have been gradually co[illegible] to the view that a contract rate [illegible] on which an equitable [illegible] when domestic consumers [illegible] ct tariff based on the ascer- [illegible] control of the consumer to make it work in practice, and as far as I know there is no such instrument on [illegible] reason to think that within [illegible]

Mr. W[illegible] special form of heater was advertised for attachment to the cold-water tap, the idea being that as the water flowed from the tap it should be heated. Extraordinary [illegible]

[illegible] not mention the temperature in the case of [illegible] oven. If the temperature of the oven was h[illegible] of the electric oven the slight diffe[illegible] waste are easily accounted for. [illegible] tures, therefore, are abs[illegible] has had some of the troubles [illegible] where it leaves the wire support, and certainly some more [illegible] insulate as well as prevent the sharp bend. In the tests on flexible wires it seems to me to [illegible] has not referred to previous wor[illegible] series of tests at the School of T[illegible] Schwartz read before the Institution * there are [illegible] of bending tests, through a right angle at a [illegible], of different samples of flexible wires. The weight used was 3 lb. as against the author's 8 ounces and 1 lb. But [illegible] the n[illegible] bends, but there is no flexible wire app[illegible] shop flexible wire which withstood 160,000. All the others [illegible] It is to be hoped that the author will in his reply compare [illegible] towns where th[illegible] experience is that it receives proper attention by t[illegible]

[illegible]

Mr. Cramp. a circuit carrying about 400 amperes which was earthed by the Corporation workmen and passed by their inspector. A single 18 S.W.G. copper wire was used and this was twisted round a loose nut on one of the switches and soldered on to the end of a lead waterpipe hanging loose from a ceiling. It is worthy of remark that in the same installation, on which three contractors had been engaged besides the Corporation, the former had put in "Home Office" fuses whilst the Corporation had put in bare wire. I think that it is not too much to say that a Corporation inspector frequently hesitates to condemn work by a Corporation department which he would not have passed had it been done by an outside contractor. It is always unsatisfactory to have the contract and inspection in the same hands.

Alderman Walker. Alderman W. WALKER: There is no doubt that the domestic load is one to be sought after. The diversity factor is very good, and although the load per house is small the accumulative effect upon even a large system like that of Manchester must be beneficial. I hold strong views as to the reason why the community is not more responsive to any tariff that can be devised in order to attract it. In Manchester a little over 12 months ago we adopted a new scale in order to increase the use of electricity in private houses; it was 12½ per cent on the rateable value, plus ½d. per unit metered. We also made it a condition that for a house rated below £30 2 kilowatts of apparatus (cookers, radiators, vacuum cleaners, etc.) must be installed; for houses between £30 and £50 it was to be 3 kilowatts, and for those over £50 4 kilowatts. The response to that tariff has been poor. I have tried to ascertain the cause and have come to the conclusion that it is owing to the inadequate wiring of the houses originally. When the would-be customer is told that it is necessary, in order to install radiators, cookers, etc., practically to rewire his house, involving disturbance of the plaster, destruction of decorations, plus additional fittings, he will not entertain the proposal. On my suggestion a circular is now sent to all builders and architects about to erect property in the city, and this contains a strong request to put in wire of a gauge sufficient to carry future additions in the way of radiator and cooking loads. We also circularize tenants who we know are going to occupy houses where electricity has been used for lighting only, and we ask them to insist that while alterations are being carried out the wiring shall be made sufficient to take the heavier load. This, perhaps, will be a hint to other supply authorities. I am confident that the capital cost given by the author is excessive for apparatus for a family of the size he mentions; he could install cooking appliances at much less expense than he has done. I have been going into some figures during the last few days but I cannot find any approaching his. It is to the interest of the manufacturer to do away with the failures which the author describes. During the last few months improvements have been made in both radiators and ovens, which will do much to make them fool-proof against careless use. As regards the question of pilot lights, I do not agree with the author. I prefer pilot lights on the separate circuits. The author advocates an indicating light on the main switch only. This does not to me seem to be of service in certain conditions. Suppose the cook has been using the largest element in the oven and the smallest hot-plate, she finishes with the oven but forgets to switch off and continues to use the hot-plate. The lamp would convey no warning whatever, as the main switch would be in the "on" position for the hot-plate. I agree as to the necessity of putting the whole of the switches over the cooker in easily accessible positions. After the experiences which the author has given I think that he is right as to the utility of a thermometer. Whilst the thermometer may not indicate the exact temperature existing in the oven, the ratio between these two will be constant, so the cook will know what ought to be indicated by the thermometer in order to have the correct heat in the oven for the work to be done. I think also that the author does not do justice to electric cooking in the figures to which Mr. Cramp referred, showing a loss of 14½ per cent of weight of meat electrically cooked as against 25 per cent where coal is used. The author will probably say that Mr. Cramp's deductions are wrong. I take the former to mean that the coal-heated oven and the electric oven at the lower heat are to be compared, because, of the other examples, he says, "the temperature in the last four cases was perhaps 50 degrees F. higher than in those cases where the loss was low." It seems evident from this that the temperature of the coal-heated oven was equal to the lower and correct temperature of the electric oven, and such a comparison gives 10½ per cent in favour of electric cooking on wastage; in most business concerns 10½ per cent is looked upon as a fair return. Although it will not pay the whole of the electricity bill it is going materially to assist in that direction. On tariffs I think that the last word has not yet been said. I strongly hold the opinion that rateable value is the best method. The rating authorities are experts, and they are careful to keep their assessments up to date. We have their rate book to appeal to without any expense to ourselves. If we are going to take appliances installed, or the maximum demand, or the number of points, or the area of rooms, many difficulties will be met and heavy expense incurred. Every house has a rateable value; the assessment is known to the tenant and forms the basis of all his dealings with the local authority. Its adoption by the electricity undertaking will be accepted as a natural development and is likely to cause less friction than any other method.

Professor Marchant. Professor E. W. MARCHANT: My own experience has been confined to small apparatus. With reference to the articles that we have used—kettles, irons, radiators, hot-plates and so forth—I entirely agree with the author that the weak spot is the flexible wire, but I do not agree with what Mr. Cramp said as to the undesirability of the springs for protecting flexible ends. In some of the apparatus which we use, the wire springs have done quite well and there has been no trouble with short-circuits. I think much is to be said in favour of the suggestion put forward by the author of having an inspector attached to the electrical engineer's department to do small repairs, who shall be available in case the apparatus breaks down. If a person, who, knowing nothing about it, calls in the local contractor to make a small repair, the latter makes it a more substantial affair than he need, and the consumer begins to think that the apparatus is not a success. Then, again, the time generally taken to repair the apparatus, when it is seriously injured, is very much too long. Designs should be used in which the heating elements

[illegible] it up who are of a different type [illegible]

[illegible]

[illegible] unit, but very little progress was made owing to the fact [illegible] There is [illegible] struction of such apparatus. [illegible] tage to have a thermometer, more particularly where the [illegible] flexible cable we have not had any complaints with respect to the breaking of connections. Such [illegible] it is now the practice to install a boiler behind the grate, not only in the kitchen, but in one or more of the living [illegible]

[illegible] charge.

[illegible]

[illegible] entirely unprejudiced by any considerations of [illegible] and giving winter [illegible] are :—(1) Less of the drudgery of housework and [illegible]

Mr. Eccles. able at any price. The total cost has been as follows for an average of three adults all the time :—

Quarter Ending		Sept 1914			Dec. 1914			March 1915		
		£	s.	d.	£	s.	d.	£	s.	d.
Electricity	...	2	10	7	2	12	1	3	4	5½
Coal ...	...	0	1	9	1	1	9	2	0	7
Gas ...	...	0	10	8	0	6	2½	0	4	0
Totals	...	3	15	0	4	0	0½	5	9	0½

This represents about £17 12s. od. per annum ; but against this there has been a saving in charwomen, laundry, carpet-cleaning, baking, etc., of about 5s. per week, or say £13 os. od. per annum. Now to take the author's case. He has not had any of the advantages detailed above, except perhaps a little extra cleanliness in cooking, and I am not surprised at his loss of £8 18s. 9d. In my case, however, the total cost per unit was 0·74d. In his case the total cost per unit was 1·09d. This difference alone would reduce his loss to £1 12s. 6d. per annum. Further, £13 10s. od. per annum for coal for 8 or 9 persons is very economical and probably much below the average. On the whole then I should say that the apparent result as given by the author is likely to be most discouraging to prospective consumers, and the average layman does not bother much about explanations. As for the cooking apparatus, there is still much to be desired both as regards cost and design. In particular, the oven ought never to be less than 16 in. × 16 in. area (plan), and the height should vary from 12 inches upwards according to the capacity required. Actually one can find but few ovens less than 20 inches high, and several are only 12 inches wide, which seems to me to be quite futile. It looks as though makers are following gas-oven practice, which is quite another problem since the bottom 6 or 8 inches is not much good for cooking and increased height is therefore necessary. The grill, I agree, is practically perfect, but where is the rapid plate-warmer which will heat say four plates in 5 minutes at a reasonable efficiency ? As for boiling-plates, my experience has been none too good, the time required being too long, the efficiency poor, and the reliability moderate. The cost of wiring leaves much to be desired, and here I feel that the local supply authorities could do a great deal more for the consumer than is done at present, by evolving a more satisfactory combination of wiring and fittings, giving the prospective consumer the benefit of their experience and not leaving him to the mercy of an unknown contractor and a book of regulations. I think it is a good suggestion to have a lightly-metal-protected twin cable with the metal sheathing properly and easily earthed and suitable fittings gripping the cable tightly so that the wiring could be quickly done and with a minimum disturbance to plaster, etc., which is a big item in a furnished house. Regarding the losses whilst roasting meats, etc., in the various types of oven, I never could see why there should be any difference between a coal-heated oven and an electrically-heated one, provided both were equally well-made and air-tight. In an ordinary gas oven, however, the conditions are different and a higher loss is only to be expected since the meat is exposed to a stream of hot air and burnt gases. The only worry I have about the tariff is to see that I am not being overcharged to cover the loss on some other consumer. What I would consider to be a fair basis would be a "primary" fixed charge to cover the capital outlay required to give me a supply (this would naturally depend mostly on the situation of my house and the maximum demand required), and then a "secondary" charge to be one covering the cost of production during the time that I wanted the current. How to apply such a basis of charging is quite another matter and one for the supply authorities to settle.

Mr. Ratcliff. Mr. H. A. RATCLIFF : I regard the paper as valuable because it is largely a record of experiences, and these are always instructive. I am glad that the author refers to the extravagant claims which have been made for electric cooking, as there is really no justification for many of them and it is unfortunate that they were ever made. Electric cooking will have to stand or fall on its merits, quite apart from questions of relative costs. I believe it took about 20 years for gas cooking to become really popular. In the days of carbon-filament lamps it could not reasonably be claimed that electric lighting compared favourably with incandescent gas as regards actual relative costs, but, nevertheless, it was popular and in great demand simply because its numerous advantages were recognized. The advantages of electric cooking will no doubt sooner or later be similarly recognized. I think that hygienic considerations will provide one of the strongest arguments in its favour, at any rate as compared with gas cooking ; for an ordinary gas oven is hardly a model of desirable hygienic conditions. The outstanding feature of gas cookers is that they are thoroughly robust, and consequently repairs are very rarely, if ever, required, with the possible exception of the occasional renewal of the grill plates. Unfortunately this has not always been the experience with electric cookers, although I am pleased to see that some of those now on the market really convey the impression that they have been manufactured in engineering workshops. The author refers to the problem of water heating, and considers that it is not financially impracticable. He states that it is a question of tariffs. If that means reducing the price of electrical energy low enough, then of course I agree, but not otherwise. At ½d. per unit, without any fixed charges, electric water heating is a luxury, at ¼d. a unit it becomes worth consideration, mainly on the score of convenience and cleanliness, and at Dr. Ferranti's ideal of ⅛d. per unit it is a reasonable financial proposition. In connection with water heating, the question of efficiency is usually somewhat ignored, although claims are occasionally made for efficiencies of 100 per cent. The highest efficiency is undoubtedly obtained with the geyser type of heater, but the relatively large kilowatt demand, and the very limited flow of water at the higher temperatures, preclude its use for domestic purposes, quite apart from the impossibility of obtaining a sufficiently low tariff for such an undesirable load. Some tests made on a heater of the geyser type, which had a loading of 7 kilowatts, showed it to have an efficiency of 98·5 per cent with an outlet temperature of 110° F., and 94·1 per cent with an outlet

[illegible]

to be undertaken lightly in view of the rapid changes at [illegible]

[illegible] rental, puts a fire in the kitchen to give [illegible]

[illegible] and that is where it is found that the efficiency of the [illegible] contact between the vessel and the heating elements. In [illegible] whatever it may be, in almost direct contact with the vessel to be heated. In the gas cooker the gas flame directly impinges on the vessel, and if a similar effect can [illegible]

[illegible] to put in [illegible]

[illegible] that the author thinks there is a future [illegible] water heating. There is no doubt that [illegible] This is probably enough for a household of the [illegible] thermometer from the heating elements [illegible] to the oven, and they can then [illegible] very accurately by placing the hand in the oven. I [illegible]

Mr. Weaving. could be obtained. With the present form of gas oven these low shrinkages cannot be obtained, owing to the current of air for combustion (together with approximately twice as much more air drawn in through the bottom of the oven) passing over the joint. The evaporative effect of a current of dry air is well known, and this is responsible for the occasional dried-up appearance and heavy shrinkage of meat cooked in a gas oven. It is immaterial whether the fluid evaporated is water or not, as it has to be paid for. Besides, water has an important influence on flavour and digestion. As an extreme instance, take the case of sugar. We all know that sugar is only carbon and water, but if all the water is driven off, the remaining carbon is unpalatable, and nobody would eat it. The saving due to smaller meat shrinkage may be only 1s. per week in an ordinary household, but even 1s. per week helps to pay for energy. I have found as the result of many trials that an ordinary cook using her own methods with gas and electric ovens will get a meat shrinkage of 25 per cent in the former, and 15 per cent in the latter. It is pleasing to see the emphasis which the author places on the necessity for earthing. This should be insisted on everywhere. For three years every piece of apparatus sent out from the firm with which I am connected has been fitted with a special earthing terminal, but I regret to say that in 50 per cent of the cases where I have seen apparatus after it has been installed, the earthing terminal has been ignored. The author's remarks regarding earthing of tumbler-switch covers apply equally well to rotary switches.

Mr. White. Mr. J. C. WHITE (*communicated*): The author complains of the high cost of wiring, particularly with steel conduit, and its inefficiency as an earth return, and he refers briefly to armoured cables as a remedy. I consider this more commercially suitable than conduit, and have had considerable experience of cab-tyre-sheathed cables for this purpose. They can be installed quite easily without damage to decorations, are not affected by grease, condensation, etc., and (another point which must be taken into consideration by central-station engineers who hire out cookers) they can be taken out of one residence and put into another without depreciating. This is an obvious advantage where the next tenant may prefer to do his cooking by gas. Such cable can be installed more cheaply than most systems. With regard to flexible wires, I think a further test ought to have been added to ascertain whether the various coverings would resist the action of grease, hot fruits boiling over, steam, water, soft soap, etc., which are risks more frequently met with than mere bends.

Mr. Cooper. Mr. W. R. COOPER (*in reply*): I am glad to have received in this discussion such strong support on the question of earthing, which I regard as a very vital matter in the proper progress of electric cooking. Mr. Weaving's remarks in this connection are significant, and I believe that his experience is by no means isolated.

I am interested to hear that Mr. Welbourn has obtained good results with asbestos-covered flexible wires. In comparing the tests by Professor Schwartz, to which Mr. Cramp has called my attention, with my own, I think the differences in the number of bends obtained are largely accounted for by the fact that the weight used by Professor Schwartz was six times as great as the weight which I used. The effect of this will be most apparent on the less flexible types. I purposely avoided high stresses, because these do not occur in practice. Mr. Cooper.

In reply to Mr. Cramp I am unable to say what was the temperature of the coal oven, as it was not fitted with a thermometer, and the cook was left to determine the temperature by the usual cook's methods.

I think the circular to which Alderman Walker refers is an excellent idea. There is no doubt that insufficient wiring is a great deterrent to the larger use of radiators.

I believe that the floor space of a house, as suggested by Professor Marchant, has been used as the basis of a tariff in the United States.

I think that Mr. Hollingsworth and some of the other speakers have omitted to notice that the figures I have given refer to a special class of consumer—one that requires a considerable amount of cooking, such as is usually associated with the continuous use of a coal range. With this point, however, I have dealt in detail in my replies to the discussions before the Institution and the Local Sections, and also with the size of cooker, which, in my opinion, was not too large. As to the primary charge at Norwich, I referred to this because some engineers take up the attitude that this part of the charge is merely in respect of the lighting part of the load. Disregarding this attitude, it may be quite desirable to maintain this charge for the load as a whole, though it is then difficult to see on what the charge is based for dealing with a load that may vary within wide limits for any one house.

With regard to water heating, it must be remembered, as Mr. Ratcliff points out, that the usual circulating system is very inefficient. If such circulating systems are merely converted to electric heating, the result again must be very inefficient, simply because heat is being continually dissipated from the pipes instead of being stored in the water. With electric heaters, only a draw-off pipe is necessary and the circulation is eliminated. Of course, in a thermal-storage system the size of the tank must be suitable to the needs of the household. For example, to replace the ordinary 50-gallon cistern by a 15-gallon electric heater would scarcely be the way to give satisfaction. It must not be forgotten that the coal-heated water supply also depends largely on thermal storage and yet has met needs so far. Mr. Weaving's suggestion of 500 watts would not give nearly enough hot water in the case I have considered, but I think this would be enough for many small flats.

The radiant hot-plate, to which Mr. Allcock refers, involves some difficult problems, and I doubt if they are yet fully appreciated. As to the merits of black versus bright ovens, I fear that this is much too controversial a subject.

I am interested in Mr. White's remarks as to the use of cab-tyre-sheathed cable for connecting up the service to cookers. This seems to provide a solution of the problem, and has the great advantages of cheapness and adaptability.

The other points in the discussion I have dealt with in my replies to the discussions in London and Birmingham.

PROCEEDINGS OF THE INSTITUTION.

ORDINARY MEETING OF 11 MARCH, 1915.

Proceedings of the 577th Ordinary Meeting of The Institution of Electrical Engineers, held on Thursday, 11 March, 1915—Sir JOHN SNELL, President, in the chair.

The minutes of the Ordinary Meeting held on [illegible] February, 1915, were taken as read and confirmed.

A paper by Mr. W. R. Cooper, Member, entitled "Electric Cooking, mainly from the Consumer's Point of View" (see page [illegible]), was read and discussed, and the meeting adjourned at [illegible] p.m.

ORDINARY MEETING OF 25 MARCH, 1915.

Proceedings of the 578th Ordinary Meeting of The Institution of Electrical Engineers, held on Thursday, 25 March, 1915—Sir JOHN SNELL, President, in the chair.

The minutes of the Ordinary Meeting held on 11 March, 1915, were taken as read and confirmed.

The list of candidates for election and transfer approved by the Council for ballot was taken as read, and was ordered to be suspended in the Hall.

At 9.25 p.m. Sir John Snell vacated the chair, which was then taken by Mr. Alexander Siemens.

A paper by Mr. W. Llewellyn Preece, Member, entitled "Telephone Troubles in the Tropics" (see page [illegible]), was read and discussed, and the meeting adjourned at 10 p.m.

ORDINARY MEETING OF 15 APRIL, 1915.

Proceedings of the 579th Ordinary Meeting of The Institution of Electrical Engineers, held on Thursday, 15 April, 1915—Sir JOHN SNELL, President, in the chair.

The minutes of the Ordinary Meeting held on 25 March, 1915, were taken as read and confirmed.

Messrs. H. [illegible] and A. T. [illegible] were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the result of the ballot was declared as follows:—

ELECTIONS.

Members.

[illegible], James.
[illegible], Edward [illegible], Lt.-Col., R.E. (T.).
[illegible], Edward Wyndham.

Associate Members.

[illegible], William.
[illegible], Cyril Vivian.
[illegible], [illegible] Lionel.

Graduates.

[illegible]
[illegible], Arthur Francis.
[illegible], Frank William.
[illegible], Hugh Reginald.
[illegible], Bernard.

[illegible]

[illegible], Robert Elias L., 2nd Lieut., R.G.A.
[illegible], George [illegible].
Winks, Arthur.

Students.

Boyland, Harold John.
[illegible], Eric Douglas.
[illegible]
[illegible]
[illegible]
Derry, Cyril.
[illegible]
[illegible]
[illegible], Harold John.
[illegible]
Hunt, Frank Ernest.

[illegible]

Lerpiniere, Edward.
[illegible], William Francis.
[illegible], Percy [illegible].
Narasingarao, Chapa Venkata L.
O'Brien, Bernard [illegible].
[illegible], Arthur Charles, 2nd Lieut., R.E. (T.).
[illegible], Edward.
[illegible]
[illegible]
Ross, Victor.
[illegible], Ernest Stuart.
[illegible], Reginald [illegible].
[illegible], John [illegible], 2nd Lieut., R.E. (T.).
[illegible], Thomas.
[illegible], Francis [illegible].
[illegible], Alfred.

TRANSFERS.

Associate Member to Member.

Aldum, Hugo.
Paris, Patrick Alfred.
Spark, James Walter.
Wadsworth, Thomas.

Graduate to Associate Member.

Bennett, Edwin John L.
Loughlin, Henry James.

Graduate to Associate Member—continued.

Woodward, Charles Hemlet.

Student to Associate Member.

Clausen, Hugh.
Elliott, Frederick Forester.
Garrett, William Basil.
Hughes, Edward, B.Sc. (Eng.).
Perryman, Nelson Joseph.

Student to Associate Member—continued.

Roberts, Leslie.
Scampton, Gregory Oliver.

Student to Graduate.

Bright, Victor Atkinson.
Delves, Francis Joseph.
Goodale, Charles Frederick.
Willis, Sydney.

The following donations were announced as having been received, and the thanks of the meeting were accorded to the donors :—

Benevolent Fund : G. F. Allom, L. B. Atkinson, S. Beeton, H. Benest, W. E. Burnand, J. Caldwell, R. A. Chattock, W. Church, C. B. Clay, F. W. Clements, Professor W. C. Clinton, W. W. Cook, V. K. Cornish, The Hon. E. H. Cozens-Hardy, I. S. Dalgleish, B. Davies, F. E. Davies, M. Deacon, Sir A. Denny, Bart., J. Devonshire, H. C. Donovan, B. M. Drake, M. G. Drake, C. V. Drysdale, D.Sc., K. Edgcumbe, W. V. Edwards, S. Evershed, E. Garcke, F. Gill, R. T. Glazebrook, C.B., D.Sc., F.R.S., G. F. C. Gordon, B. B. Granger, F. E. Gripper, C. W. Gwyther, R. Hammond, H. T. Harrison, W. V. Haslam, C. C. Hawkins, M.A., W. C. C. Hawtayne, K. Hedges, F. Higgins, J. S. Highfield, H. C. Holroyd, B. M. Jenkin, G. Kapp, D.Eng., W. T. Kerr, A. E. Levin, P. V. Luke, C.I.E., Sir Henry Mance, C.I.E., LL.D., H. Marryat, J. W. Meares, C. H. Merz, L. B. Miller, C. Mittelhausen, W. M. Mordey, K. A. Mountain, W. C. Mountain, A. M. J. Ogilvie, C.B., C. Oliver, E. Parry, The Hon. Sir C. A. Parsons, K.C.B., F.R.S., W. H. Patchell, F. S. Payne, F. Pooley, A. H. Preece, W. L. Preece, G. S. Ram, T. Rich, R. Robertson, B.Sc., S. R. Roget, B.A., J. H. Rosenthal, S. A. Russell, A. G. Seaman, E. Seddon, A. Siemens, H. C. Silver, M. G. Simpson, D. Sinclair, H. Skelton, H. A. Skelton, Sir John Snell, C. P. Sparks, A. J. Stubbs, H. W. Sullivan, W. C. P. Tapper, E. E. Tasker, W. Thom, W. W. Thomas, C. H. R. Thorn, A. P. Trotter, B.A., C. Turnbull, E. O. Walker, C.I.E., T. S. Watney, H. D. Wilkinson, W. B. Woodhouse, J. H. Woodward, H. E. Yerbury, and W. Young.

Building Fund : Professor A. Hay, D.Sc., W. M. Mordey, and Sir John Snell.

Library : Messrs. Alabaster, Gatehouse & Co., The Association of Mining Electrical Engineers, The Engineering Standards Committee, J. Erskine-Murray, D.Sc., The Institution of Railway Signal Engineers, G. D. Knox, La Lumière Electrique, The Patent Office, J. T. Peddie, A. Russell, D.Sc., F. Shaw, B.Sc., Messrs. E. & F. N. Spon, Ltd., G. Tucker, and G. W. Worrall, D.Eng.

Museum : K. Hedges.

A paper by Mr. J. H. Rider, Member, entitled "The Power Supply of the Central Mining-Rand Mines Group" (see page 609), was read and discussed, and the meeting adjourned at 9.50 p.m.

INSTITUTION ANNOUNCEMENTS.

CONVERSAZIONE.

The Annual Conversazione of the Institution will not be held this year.

THE INSTITUTE OF METALS.

Members are invited to a meeting of the Institute of Metals to be held in the Lecture Theatre of the Institution on the 12th May, 1915, at 8.30 p.m., when Sir J. J. Thomson, O.M., will deliver a lecture on "The Passage of Electricity through Metals."

ACCESSIONS TO THE REFERENCE LIBRARY.

ERSKINE-MURRAY, J. A handbook of wireless telegraphy : its theory and practice.
5th ed. 8vo. 458 pp. *London,* 1914

JERVIS-SMITH, F. J. Dynamometers. Edited and amplified by C. V. Boys. 8vo. 283 pp. *London,* 1915

MACOMBER, G. S. Modern land and submarine telegraphy. A brief up-to-date treatise on the electric telegraph, etc. 8vo. 93 pp. *Chicago,* 1914

MURDOCH, W. H. F., and OSCHWALD, V. A. Electrical instruments in theory and practice.
sm. 8vo. 374 pp. *London,* 1915

PEDDIE, J. T. First principles of production. A study of the first principles of production and the relation of science to industry. 8vo. 231 pp. *London,* 1915

RUSSELL, A. A treatise on the theory of alternating currents. 2nd ed. vol. 1. 8vo. 548 pp. *Cambridge,* 1914

SHAW, F. Electrical engineering : a first year course.
8vo. 154 pp. *London,* 1914

THE JOURNAL OF

The Institution of Electrical Engineers

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THE BOMBAY HYDRO-ELECTRIC SCHEME

[illegible]

[illegible]

[illegible] Bombay, principally for power in cotton mills.

[illegible] the water is conveyed in an open duct to the forebay, and thence through pipe lines to the power house, a distance of 13,000 feet, in which length there is a fall of 1,725 feet.

[illegible] 100,000 volts.

[illegible] equipments.

[illegible]

Lonawla is a storage lake intended principally for use [illegible]

The following are the main points of interest in con- [illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Lonawla ...	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Walwhan ...	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Shirawta ...	2,158	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

The power house is situated at a place known as Khopoli, [illegible]

The present scheme is to install in the power house eight sets, each of 11,000 b.h.p., and in the receiving station the plant necessary to deal with the power-house output. [illegible] the remaining three sets will be put down as water becomes available.

[illegible]

[illegible]

lowest level of the valley, across the head waters of the Indravani River. The dam has ample waste escapes, scouring sluices, and outlet sluices, and the top carries a roadway with parapets on each side.

Walwhan dam is 4,500 feet long and 75 feet high to the bottom of the foundations and 68 feet above the lowest level of the valley. The dam is provided with waste escapes and ample sluices of large dimensions, and the top carries a footpath with parapets on each side.

Shirawta dam is 8,000 feet long and 100 feet high to the bottom of the foundations, and 92 feet above the lowest level of the valley. The dam is provided with a waste-weir 2,470 feet long, and the top will carry a footpath with parapets on each side.

The dams are designed so that the resultant of the water pressure and the dam weight at any height cuts the base at the height within the middle third of the thickness, the weight of masonry being taken at 156 lb. per cubic foot; and at no other point either with the lake full or empty is the pressure on either edge to exceed 6 tons per square foot. The total quantity of rubble masonry in the three dams is 926,000 cubic yards. The outlet of Shirawta Lake is connected to Walwhan Lake by a tunnel 5,000 feet long through the hills, the formation being hard trap rock. At the inlet of this tunnel there is a head wall containing ample sluices to allow Shirawta Lake to be discharged into Walwhan Lake as desired to meet the required conditions of draw off.

In the dams and head wall the sluices are of the "Stoney" type in which the pressure against the sluice is transferred to the fixed work through systems of free rollers which greatly reduce the friction compared with simple sliding gates, so that the weight of the sluice itself is ample for closing purposes under the worst conditions. The sluices are built up of wrought-steel plates and sections, provision being made for reducing the leakage to the required amount by an adjustable stanchion bar on the top of the gate, which shuts on to the lintel simultaneously with the sluice skin shutting on to the sill, and two adjustable side bars which can be adjusted when the sluice is closed from the downstream side. The grooves, lintel, and sill are of cast iron built into the masonry of the dam, the grooves being provided with shield plates for protecting the rollers from the force of the water, an important point as regards the durability of the rollers and roller paths.

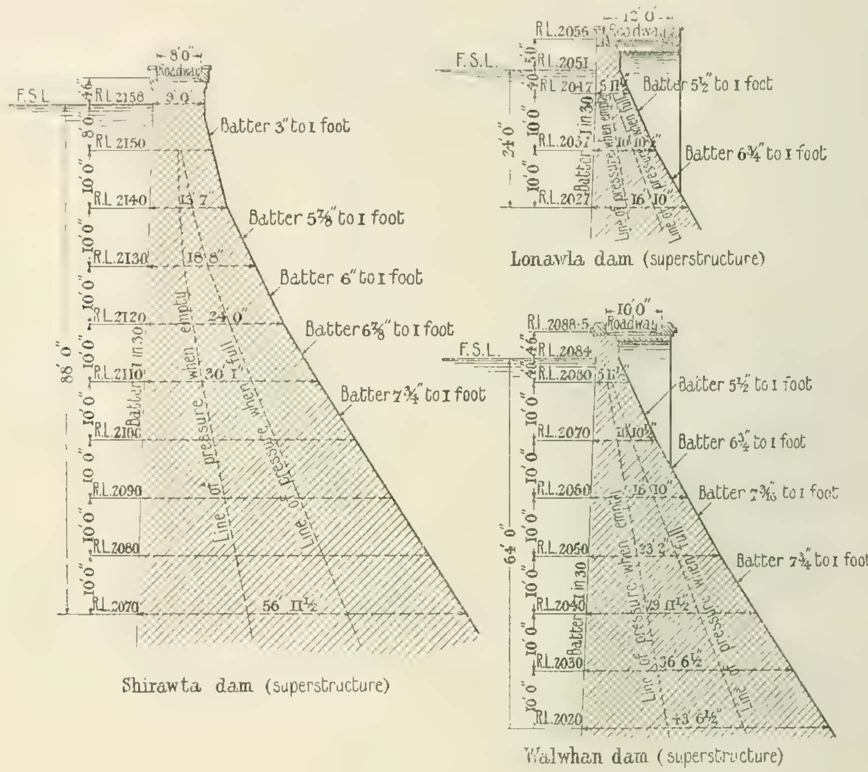


FIG. 1.—Section of Dams.

To reduce the labour of lifting the sluices, concrete counter blocks are provided, suspended on pitch chains passing round sprocket wheels driven by spur gearing. The ease of the operation is such that one man working the lifting crab of the 6 ft. and 7 ft. sluices can open or close them at the rate of 1·75 feet per minute.

There are in all 13 sluices, four 5 feet × 5 feet for operating against a head of 74 feet, five 6 feet × 7 feet for operating against a head of 52 feet, and four 6 feet × 7 feet for operating against a head of 25 feet. Sluice-gear houses are provided built of coursed rubble masonry rough dressed with domen of brick in Portland cement and mortar rendered with Portland cement inside and out.

For scouring purposes another type of sluice is used having frames and doors of cast iron with gunmetal faces

[illegible]

[illegible]

[illegible]

stone and burnt brick in equal proportions.

[illegible]

to remedy the defects.

[illegible] old samples 45 to 48 tons per square foot. [illegible]

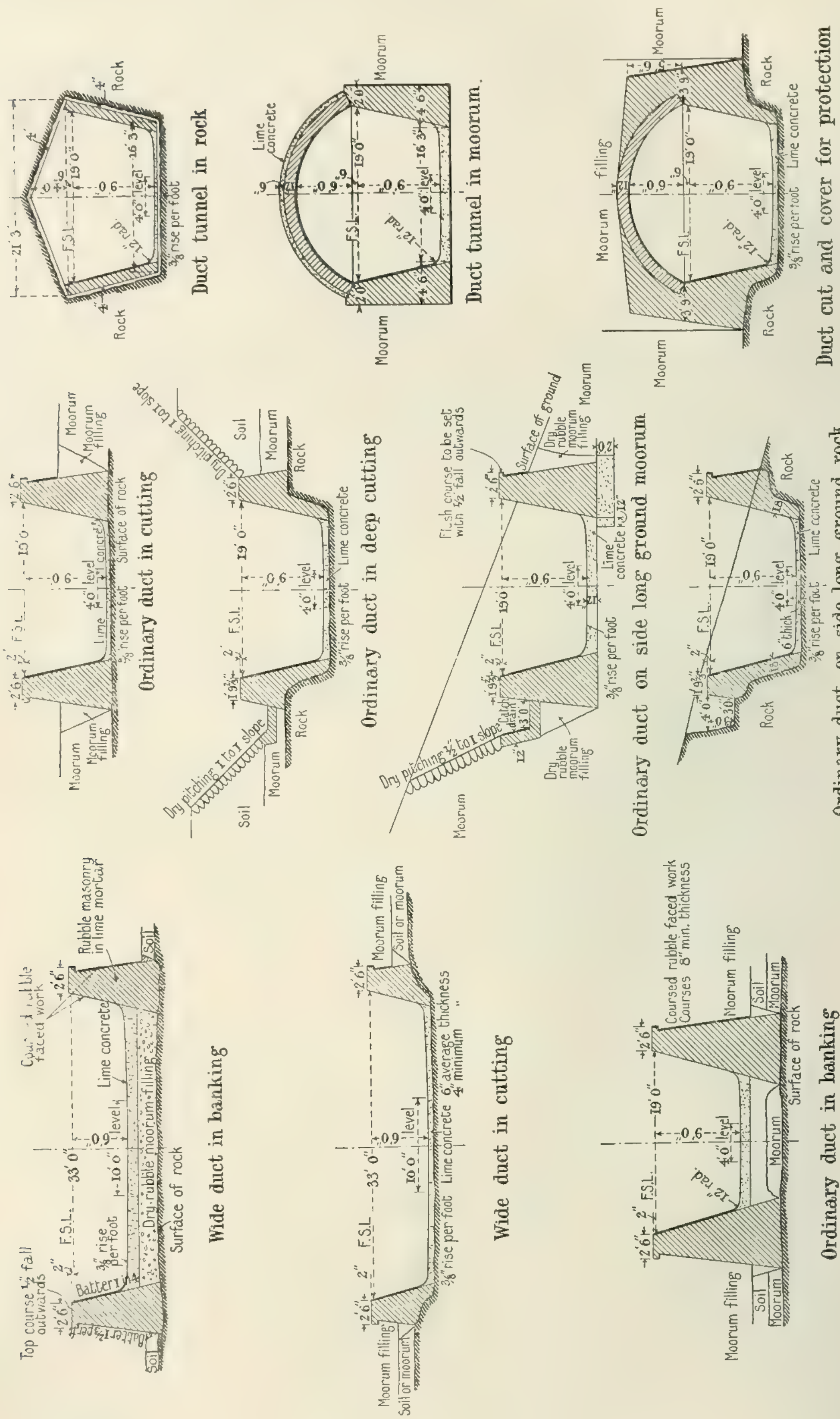


FIG. 3.—Cross-sections of Ducts.

The country through which the ducts pass is very difficult, necessitating the construction of [illegible] aqueducts made up of arches as follows:—

[illegible]

There are three tunnels [illegible] rock, one being [illegible] feet in length [illegible]

[illegible]

It will be seen from Fig. [illegible] [illegible]

Forebay.

The forebay (Fig. 4) has a storage capacity [illegible]

Fig. 3.—Plan of Forebay.

[illegible] In addition there are [illegible] tunnels having a combined length of [illegible]

[illegible]

[illegible] In many places extensive protection works have had to be constructed. [illegible]

[illegible] made up of sectional iron plates and angle irons connected together by riveted seams. [illegible]

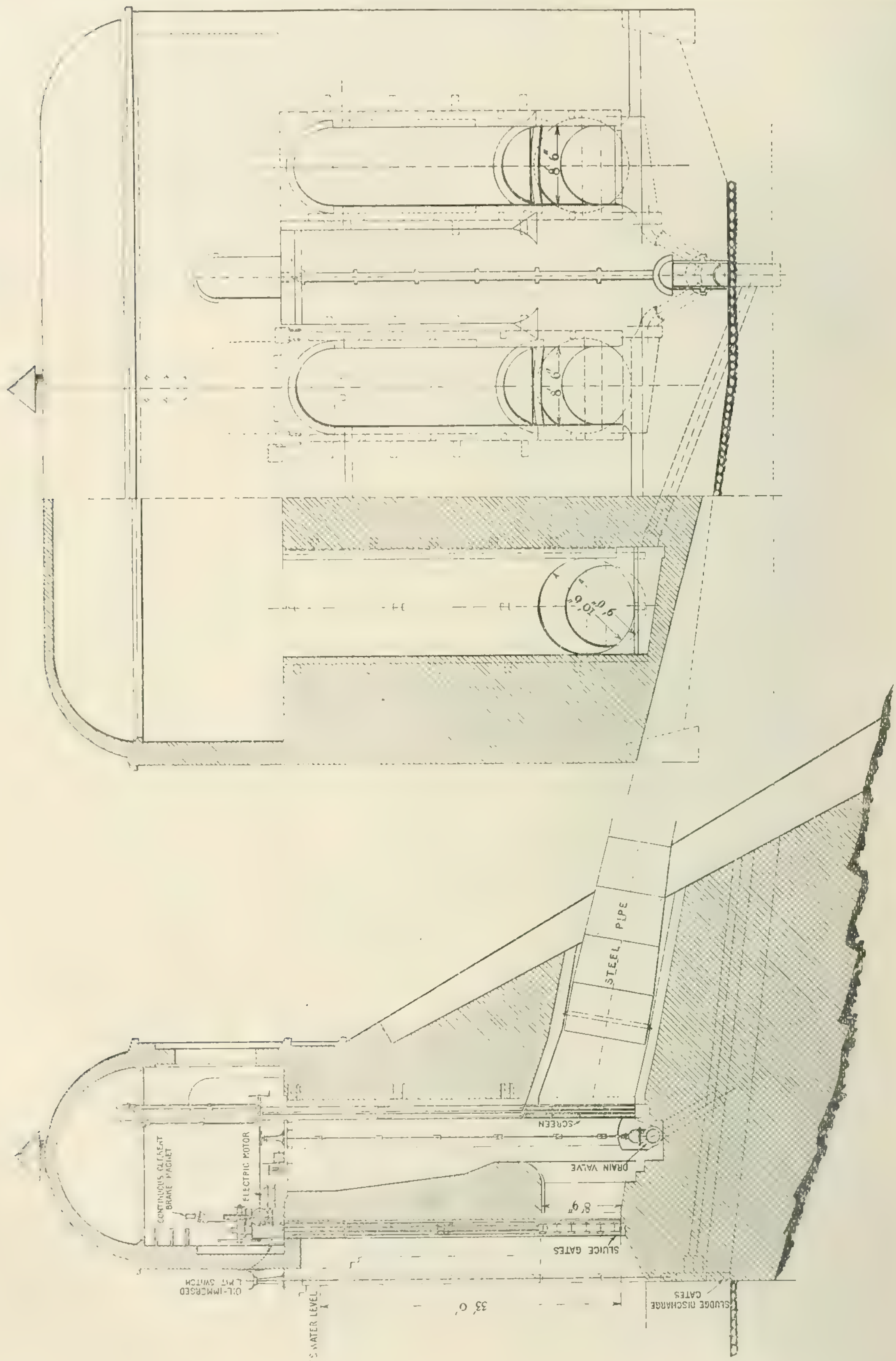


FIG. 5.—Headgate Equipment.

PIPE LINE

conveys the water down the cliffs

power house at Khopoli in the

pipe, and four lower pipe lines, the

total length

in the upper pipe line

The welded

power house floor-level 309 feet above the mean sea-level, giving a static head of 1,725 feet to the centre of the turbine gate, with a pipe pressure of 743 lb. per square inch. With four turbines, each running at 11,000 b.h.p., the total loss of head is 66 feet. The pipe line is capable of supplying water simultaneously to four main turbines and two exciter turbines, with provision for connecting one additional main turbine to the upper pipe line.

The whole of this pipe work was tested at the maker's works before shipment by hydraulic pressure to 50 per cent in excess of the static pressure to which each length is subjected in service in the case of the straight pipes, and with hot petroleum in the case of bends; and physical test certificates of the steel plates used in manufacture were submitted for approval before rolling.

A profile of the pipe line is shown in Fig. 6.

Power House.

The scheme has been designed for a normal plant capacity of 88,000 horse-power in eight main 11,000-h.p. sets, two 850-h.p. exciter sets, eight step-up 3-phase 10,000 k.v.a. transformer banks with the necessary switchgear, station auxiliary apparatus, and four outgoing lines.

The present building (Figs. 7 and 8), which is capable of extension as required, will take five main and two exciter sets, five transformer banks, switchgear, and auxiliaries, and two outgoing lines, of which five complete units are now being installed with two outgoing lines. The building consists of a turbine and generator room, spanned by a 67-ton electric travelling crane, 5,000-volt busbar and oil-switch rooms, transformer compartments with a tramway passage and turntable for handling the transformers by means of trucks, a repair shop, all these being on the ground floor, together with a 100,000-volt busbar and oil-switch room and transmission-line outlet tower located on the floors above.

The main sets consist of Escher-Wyss hydraulic impulse turbines of the horizontal type running at 300 r.p.m. and direct-coupled to Siemens Brothers 3-phase generators. The exciter sets consist of Escher-Wyss tangential wheels, running at 600 r.p.m. and direct-coupled to Siemens Brothers compound-wound generators.

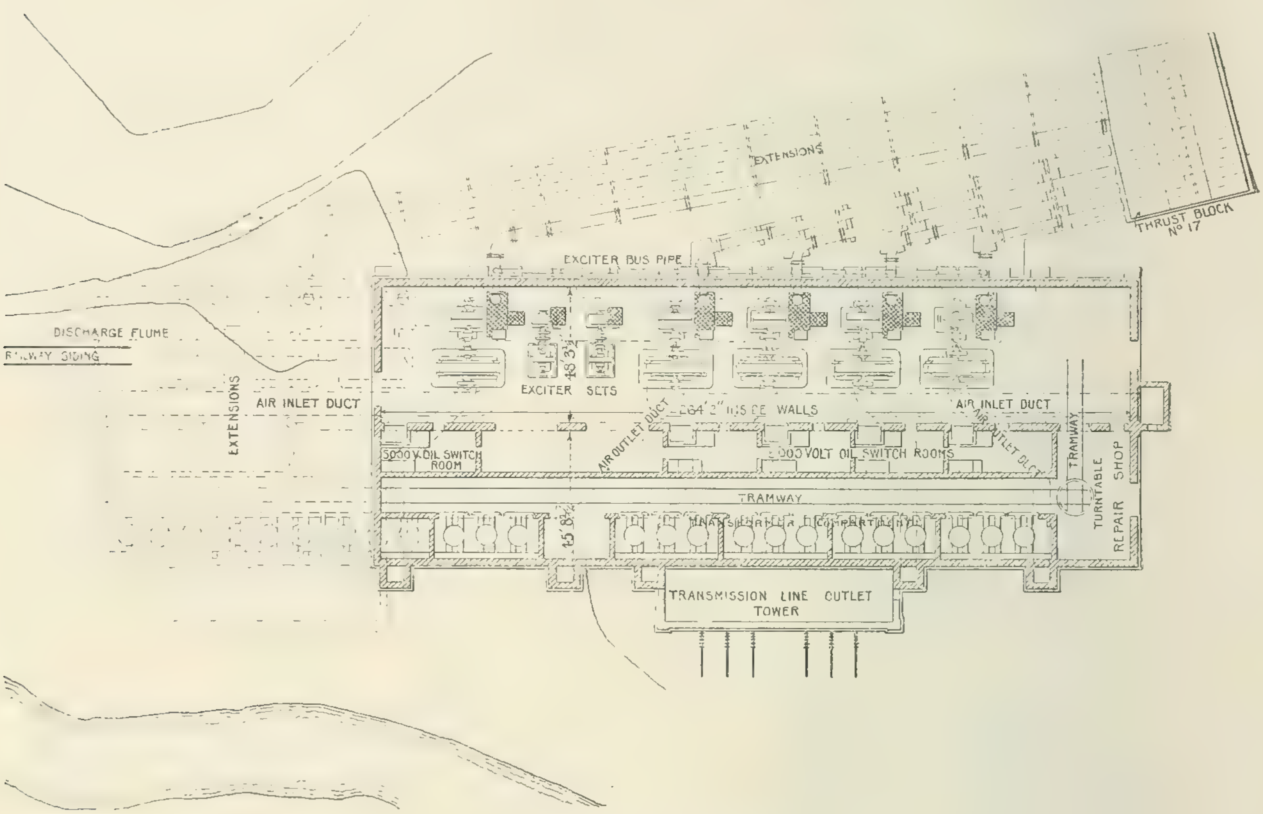
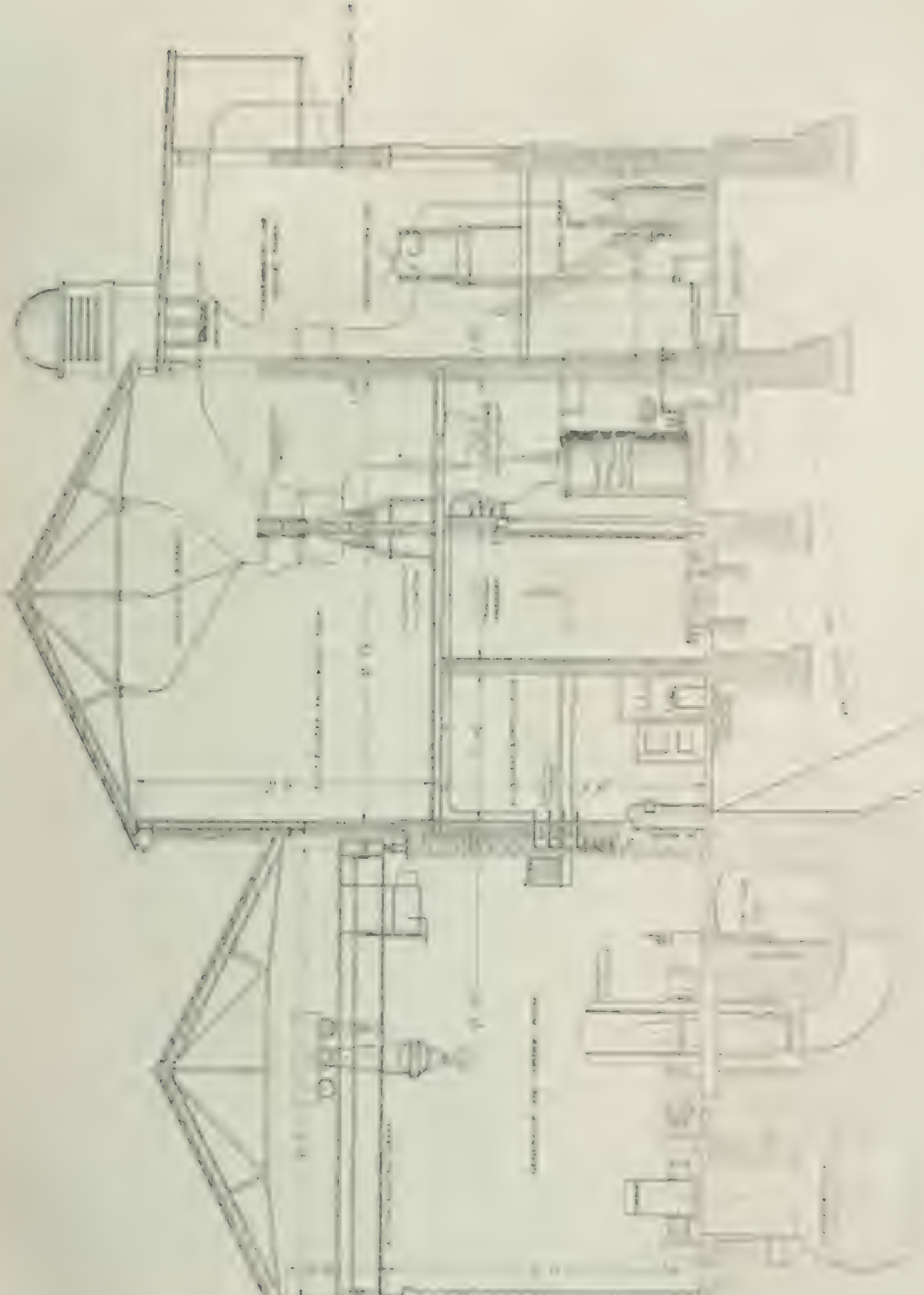


Fig 7.—Plan of Power House.

The turbine wheels consist of cast-steel discs and buckets carried by Siemens-Martin steel shafts with two ring-lubricating bearings provided with water cooling. The nozzles are of the cast-steel deflecting type, and the governors are of the oil-pressure type fitted with hydraulic automatic servo-motors, guaranteed to limit the speed variation to $2\frac{1}{2}$, 5, and 12 per cent when 25, 50, and 100 per cent of the load is suddenly thrown off. The deflecting nozzle is fitted in the inlet pipe by means of two bearings and is made watertight on both sides by means of leather washers. It is operated by the servo-motor, which consists of a casing with a differential piston, of which the lower small piston is under constant water pressure and the upper large piston under variable water pressure. A dash-pot connects the deflecting nozzle and the automatic speed governor, only the needle being



connected rigidly to the governor. The whole regulating mechanism is operated by this oil-pressure governor, the action being as follows :—

In the event of a sudden closing movement, the servo-motor lifts the lever of the main regulation shaft and also the dash-pot. The discharge valve located immediately below the latter opens a slot through which the water above the piston can escape. The piston of the servo-motor and the rear end of the complete deflecting nozzle are lifted, and the jet is diverted from the runner-wheel, the levers being so arranged that during this operation there is no movement of the needle to close the nozzle, thus guarding against an increase of pressure in the pipe line. The nozzle then begins to return to its normal position, the needle at the same time decreasing and closing the jet outlet. This movement is followed automatically by the action of the dash-pot, the piston slowly sinking and closing the discharge valve situated below, when water under pressure enters the large cylinder of the servo-motor by a pipe in which an adjustable diaphragm is fitted in front of the inlet to the chamber. The servo-motor piston is thus forced downwards and the deflecting nozzle returned to its normal position. With a slow closing movement of the regulator the nozzle is not deflected owing to the slow movement of the dash-pot piston, the needle being slowly operated directly from the regulator. With an opening movement of the regulator the nozzle is simply opened as in the case where no deflecting mechanism is used. The thrust in the inlet bend, caused by the deflection of the water, is taken up by a thrust plate fitted in the end cover of the outside bearing, the bearings being connected by four strong rods.

The exciter turbines have separately-fitted cast-steel buckets, with similar governors guaranteed to limit the speed to 3, 6, and 16 per cent when 25, 50, and 100 per cent of the load is suddenly thrown off. The guaranteed full-load efficiency is 82 per cent for the main, and 77 per cent for the exciter turbines.

The main generators are of the rotating-field totally-enclosed type, designed for a normal load rating of 8,000 kilowatts at a power factor of 0·8 and 4,000 to 5,300 volts 50 periods, 3-phase, with a temperature rise not exceeding 60 degrees F. above air at 110° F., and 20 per cent overload for 10 hours without injury. The full-load efficiency at 0·8 power factor is 94·3 per cent, with an inherent regulation of 9 per cent at unity and 22 per cent at 0·8 power factor. Induced ventilation is provided by means of fans on the rotor shafts, each machine being connected to the main inlet air-duct by a shutter and to the outlet air-duct to the atmosphere. These shutters are motor-operated with automatic control, so arranged that when the field switches are closed the shutters are open, and vice versa. The bearings are supplied with oil under pressure and are provided with water cooling.

The exciters are compound-wound machines designed for a full-load rating of 600 kilowatts at 250 volts, and 20 per cent overload, the full-load efficiency being 93 per cent. The energy required for excitation at full-load and unity power factor is 25 kilowatts and at 0·8 power factor is 38 kilowatts.

Each 3-phase transformer bank consists of three single-phase General Electric, oil-immersed, water-cooled, static transformers, delta-delta connected and designed for a full-load output of 3,333 k.v.a. at 0·8 power factor when stepping up from 5,000 to 100,000 volts, 50 periods, the temperature rise not exceeding 70 degrees F. above cooling water at 75° F., with a water circulation of 950 gallons per hour. These sets are capable of 20 per cent overload for 10 hours with a water circulation of 1,200 gallons per hour without injurious heating.

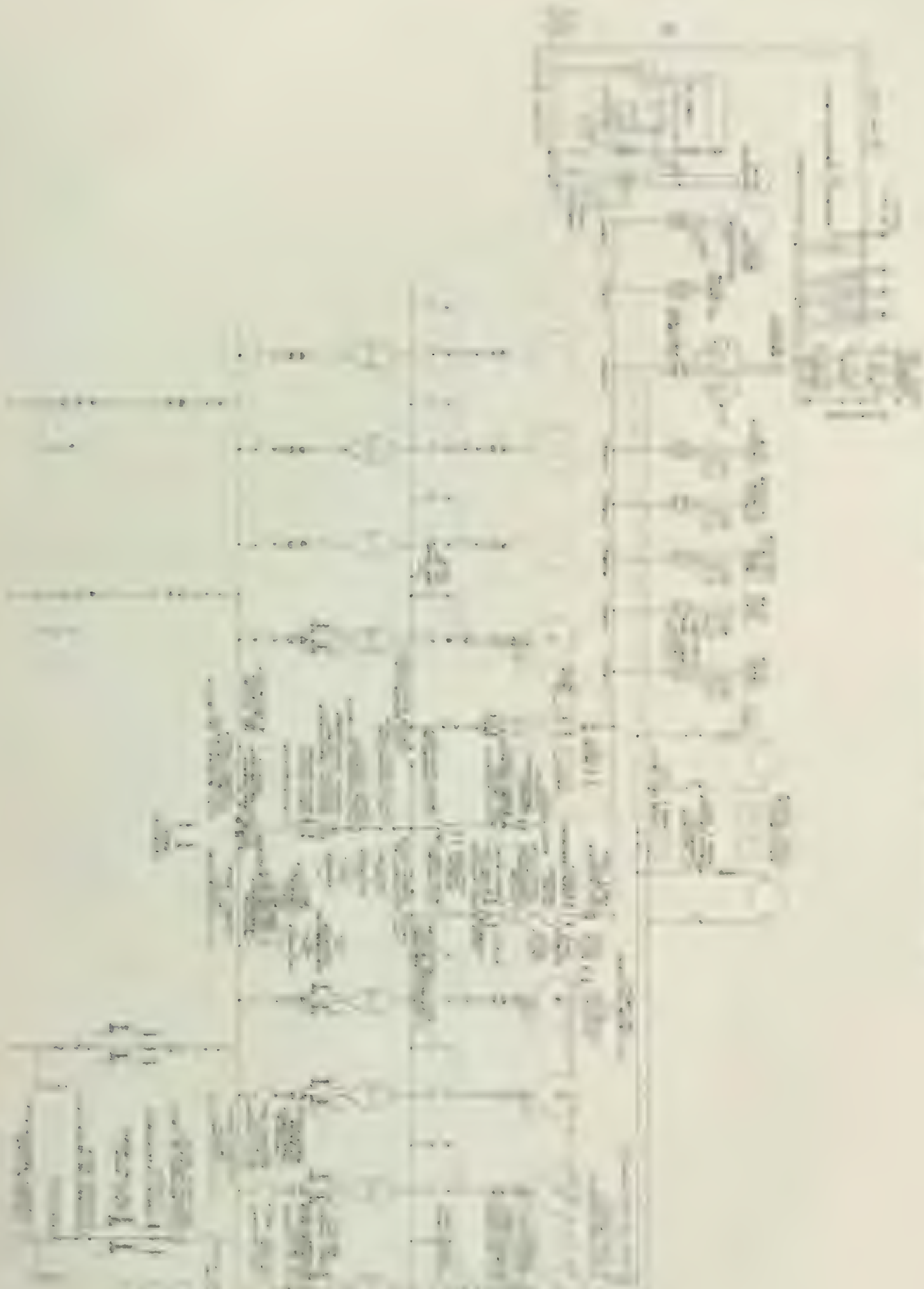
The full-load efficiency at 0·8 power factor is 98·1 per cent, and the efficiency at half load is 97·2 per cent. The regulation is 0·8 per cent at unity power factor, and 4·6 per cent at 0·8 power factor.

The transformers are of the shell type, having flat primary and secondary coils placed vertically and surrounded by a laminated sheet-steel core, the design and arrangement being such that the heat is conveyed from the interior to the water-cooling coils and tank by natural circulation.

The tanks are of boiler-plate steel, cylindrical in form. They are provided with lugs for lifting the complete transformer and are supported on a cast-iron base, all the joints being made oil-tight by heavy riveting and caulking. The covers, which are of steel plate, are provided with a manhole for giving access to the internal connection board, and are arranged for being lifted separately or with the coils and core. The fittings include an oil gauge, a thermometer, a draw-off cock, and flanged wheels. The terminal leads from the primary and secondary windings are brought out through the cover by suitable bushings of ample surface to prevent leakage. The high-tension bushings are of the compound-filled type and consist of a conductor rod from the top to the bottom which is surrounded by several concentric press-board insulating cylinders, separated by spaces, outside which the exterior wall of the bushing is built up of a number of annular rings of moulded insulating compound, interspaced with impregnated press-board discs of larger diameter than the rings in order to prevent leakage. These discs and rings are cemented together and are tightly clamped by nuts at the top and bottom of the rod. The bushings are supported on cast-iron rings attached to the cover. The low-tension bushings are of porcelain.

The principal dimensions of the transformers are as follows :—Height to the top of the high-tension lead 16 feet, and to the cover 13 feet ; diameter of the tank 8 feet. The weight when assembled and filled with oil is 24 tons, of which the core and coils account for 11 tons. The quantity of oil required for filling is 2,300 gallons, and weighs 8 tons. The oil used is a specially-prepared mineral oil, treated before filling, and from time to time in service, in a drying and purifying outfit in order to remove moisture and foreign matter, which affects or endangers the insulating properties of the oil. This outfit consists of a portable set comprising a filter-press, a motor-driven centrifugal pump, and a strainer, and is mounted on a truck. It is capable of treating 1,500 gallons of oil per hour, the filtering medium being blotting paper.

Provision is made in the oil-pipe system for connecting this set to any transformer the oil of which requires treatment. The oil is tested in a standard testing set, consisting of an oil receptacle with a 0·2 in. spark-gap and contacts, and a testing transformer, and the oil is filtered until the puncture voltage is raised to 40,000 volts.



The water supply for the cooling coils is obtained from the pipe line through a reducing valve, a tank being provided for the system, whence the water is fed by gravity at an inlet head of about 20 feet through the necessary piping and valves connecting up the three coils placed in the upper part of each tank, where they are constantly in contact with the heated oil rising from the windings and core.

Each bank of transformers on overload rating takes 3,600 gallons of water per hour at a temperature of 75° F., and the total requirements of the plant now being installed will be 18,000 gallons of water per hour.

The coils are made of heavy lap-welded wrought-iron pipe with electrically-welded joints, and are subjected to an oil test-pressure of 1,000 lb. per square inch. Each inlet pipe is provided with a water-flow indicator and a discharge alarm.

The oil-supply service comprises an oil sump, a filtered-oil tank, pipes and valves to the transformers, and an oil pump.

The sump and transformer inlet-valve levels are arranged so that the transformers are emptied by gravity, and the oil is pumped from the sump to the filtered-oil tank by means of the portable oil-treating set, the oil passing through the filter press.

The oil-pump set consists of a single-stage turbine-pump direct-coupled to a 5-h.p. 440-volt 50-period 3-phase induction motor running at 2,900 r.p.m. This pump has a capacity of 3,000 gallons per hour against a head of 60 feet.

The diagram of connections of the switchgear system is shown in Fig. 9. Provision is made for operating each main unit with its own transformer bank, or through the 5,000-volt transfer busbar with any bank as required, and on the high-tension side the transformer banks and outgoing lines are operated in parallel.

The equipment consists of remote-control, electrically-operated oil switches and other apparatus operated from the benchboard located on a gallery overlooking the generator room at a point which will eventually be the centre of the building.

The apparatus in the generator circuits consists of three single-pole, non-automatic, solenoid-operated oil switches in cell compartments, disconnecting switches, and current and potential transformers; and in the high-tension side of the transformer banks three single-pole, automatic, solenoid-operated oil switches in tanks, disconnecting switches, and series relays; and similar equipments in the outgoing lines with the addition of current transformers, choke coils, and lightning-arrester equipment.

The high-tension oil switches are automatically tripped by inverse time-limit, overload, series relays which are mounted on post insulators, a long rod from the relay closing a switch on the wall in the opening-coil circuits of the solenoids in the control wiring. Each switch unit is designed to operate as one switch with a breaking capacity of 40,000 k.v.a.

The transfer busbar system consists of a copper bar carried on insulators and sectionalized by means of disconnecting switches, and the high-tension busbar system of copper tubing which is carried on post insulators, suspended from the roof, sectionalized with disconnecting switches and provided with three single-pole, automatic, solenoid-operated oil switches in tanks between the fourth and fifth banks. This switch is tripped by means of inverse time-limit, overload relays in connection with current transformers.

The low-tension wiring consists of varnished cambric-insulated, fireproof-treated cables, and the high-tension copper tubing on post insulators arranged for a phase-spacing of 5 feet and a striking distance to earth of 3 feet, the circuits being taken through the roof of the transformer compartments in compound-filled bushings.

The switchgear equipment in the water-rheostat testing circuit consists of three single-pole automatic solenoid-operated oil switches, current transformers, and a disconnecting switch, and in the testing-transformer circuit a triple-pole, automatic, motor-operated oil switch, instantaneous overload series relays, current and potential transformers, a disconnecting switch, and a voltage regulator.

This transformer has a capacity of 100 k.v.a. and transforms from 5,000 to 200,000 volts, 50 periods, single-phase.

The switchgear equipment in the duplicate station transformer circuits from the transfer busbar consists of triple-pole, automatic, motor-operated oil switches, instantaneous, overload series relays, and disconnecting switches.

The benchboard, which is capable of extension as required, is built of blue Vermont marble panels, mounted on pipe supports, with grille work at the back fitted with the necessary instruments, control switches, and indicating lamps, a mimic busbar system of remote-control apparatus for operating the generators and transformer banks, exciters, outgoing lines, station transformers, a testing transformer, and a water-rheostat testing equipment. Calibrating and testing terminals are provided and also a swinging bracket carrying illuminated-dial voltmeters and a synchronism indicator. For signalling to the generator-room floor a complete signal system is installed, with a signal stand near each generator.

The control switches are of the "push and pull" button type, single-pole double-throw, a green pilot lamp indicating the open position of the oil switches, and a red pilot lamp the closed position.

The system is operated at 220 volts from a 60-ampere 8-hour battery, or from the 18 kw. motor-generator charging set if required.

From this supply are also operated the motors of the generator field-rheostats, air-duct shutters, and turbine governors.

The auxiliary switchboard controls the supply from the two 312 k.v.a. 5,000/440-volt 50-period 3-phase transformers for station power and lighting. It is built of blue Vermont marble panels, carried on pipe supports. There are two transformer panels, six double feeder panels, a lighting panel, and a battery and motor-generator panel.

The busbars are of copper bar and are carried on insulators at the back of the board. The oil switches are of the triple-pole, automatic, hand-operated type, and are fixed behind the board, the transformer circuits having current transformers and inverse time-limit overload relays, and the power circuits trip coils for automatic protection.

Voltage regulators are installed for maintaining a constant voltage on the busbars.

The lighting supply is furnished from three 30-kw. 440/220-volt 50-period single-phase transformers.

[illegible]

[illegible]

[illegible] pressure-rises are provided with [illegible]

random from each coil during manufacture and are tested in tension and torsion machines. The mechanical tests are a breaking stress of 5,400 lb., an elongation of 1 per cent in six inches, an elastic limit of 3,800 lb., a torsional test of 15 twists in three inches, and a wrapping test of six times round its own diameter, unwrapped and re-wrapped.

For the creek-crossing spans a 7-strand hard-drawn silicon bronze conductor is used, having an area of 0·169 square inch, a weight between the limits of 648 and 676 lb. per 1,000 feet, and a resistance of 0·514 ohm per mile at 60° F.

The mechanical tests are a breaking stress of 14,000 lb., an elongation of $1\frac{1}{4}$ per cent in six inches, and an elastic limit of 10,500 lb. A torsional test of 8 twists in six inches, and a wrapping test of six times round its own diameter unwrapped and re-wrapped.

Individual wires of each conductor are drawn in as long lengths as possible, and where joints are used they are silver brazed, the conductors being supplied in standard lengths of 2,200 yards.

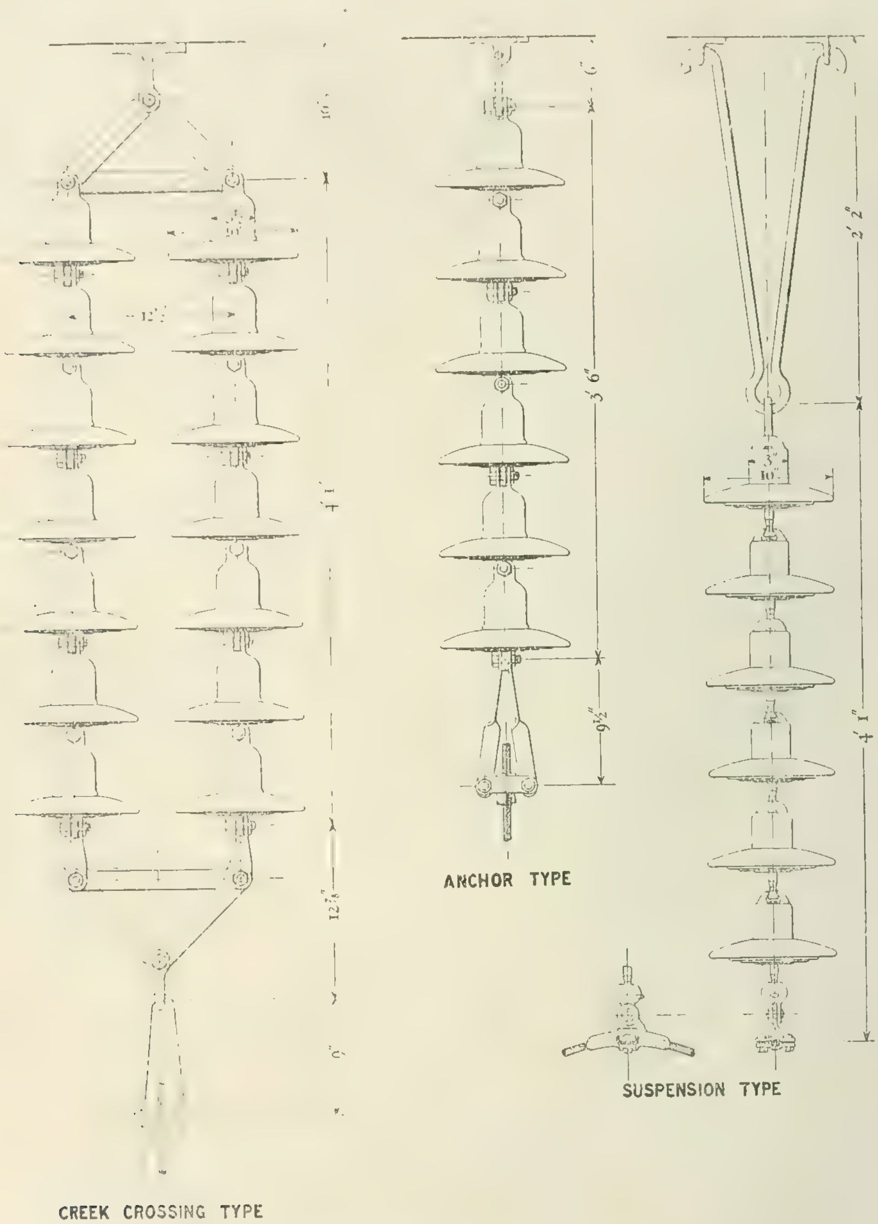


Fig. 11.—Transmission-line Insulators.

For jointing up on the site a twisted-sleeve mechanical joint is used, which is made by passing the two ends of the conductors in opposite directions through a copper sleeve, then clamping the wires and sleeve together with two clamps and rotating the clamps in opposite directions until the joint is made in several complete twists.

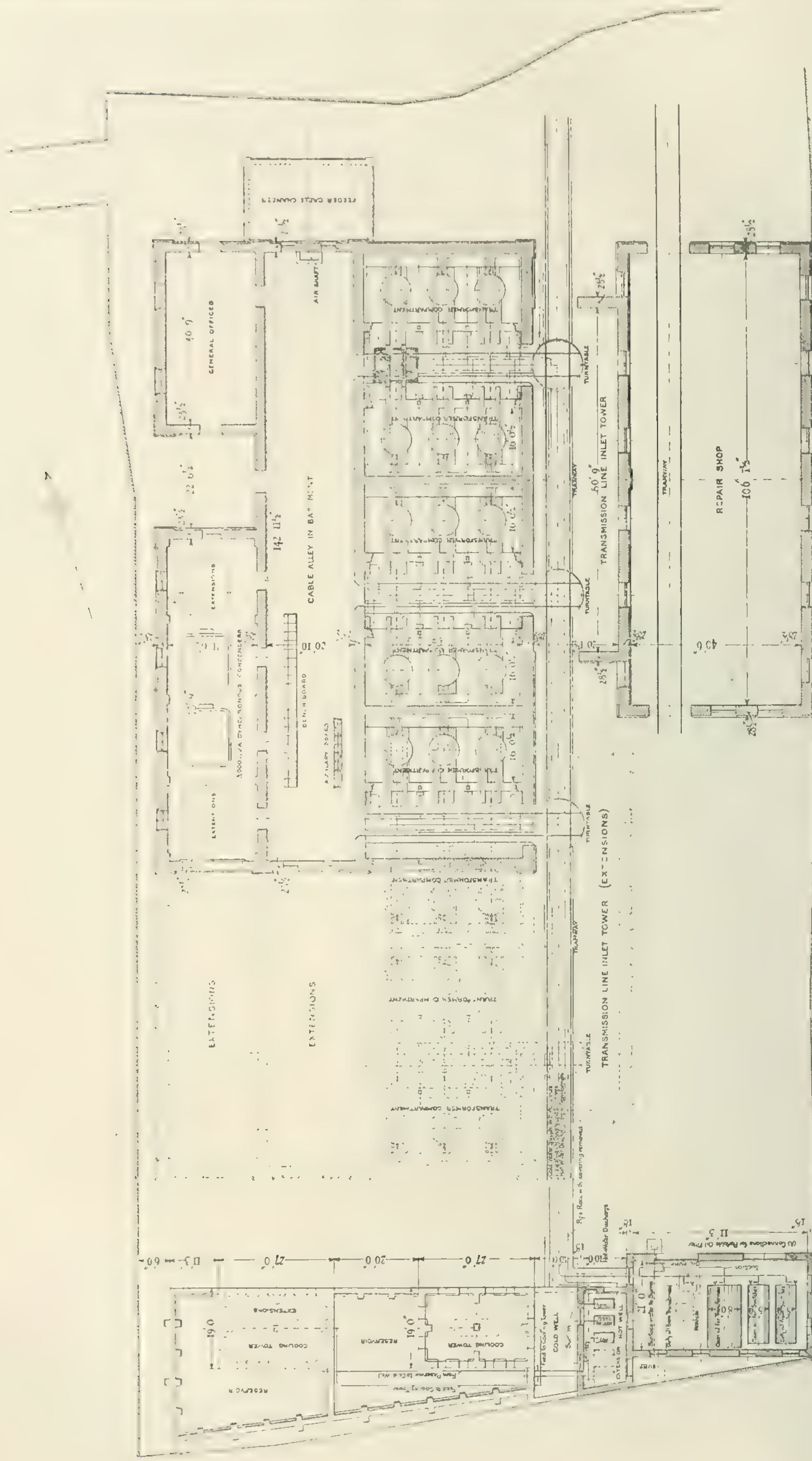


FIG. 13.—Receiving Station.

[illegible]

The telephone equipment consists of two circuits of [illegible] On the land portion of the line the [illegible] on each side of the towers, and are carried on trans-position pin-type insulators, intermediate telephone poles [illegible] circuits are placed above the power circuits. The instru-[illegible] between the speaking and ringing apparatus and the line, and hearing takes place through a rubber tube, which provides for safety in the event of the telephone [illegible]

For removing static disturbances in the telephone line in [illegible]

[illegible] factor with a temperature rise not exceed[illegible] sions, and weights.

The oil-supply service is a duplicate of the power-house [illegible] sets are supplied.

[illegible] from an inlet temperature of 107° F. to an outlet temper-ature of 87° F. with a wet-bulb temperature of 80° F. They are built of teak frames and posts, with bars and laths of jungle wood, and are treated with preservative [illegible]

[illegible] against a total head of 45 feet. One pump circulates the [illegible] situated beneath the tower, and another pump lifts the [illegible]

For improving the power factor and regulation of the system, duplicate synchronous-condenser sets are provided, each consisting of a 6,600-volt, 50-cycle, 500 r.p.m., 3-phase synchronous motor with a 125-volt exciter on the overhung part of the shaft.

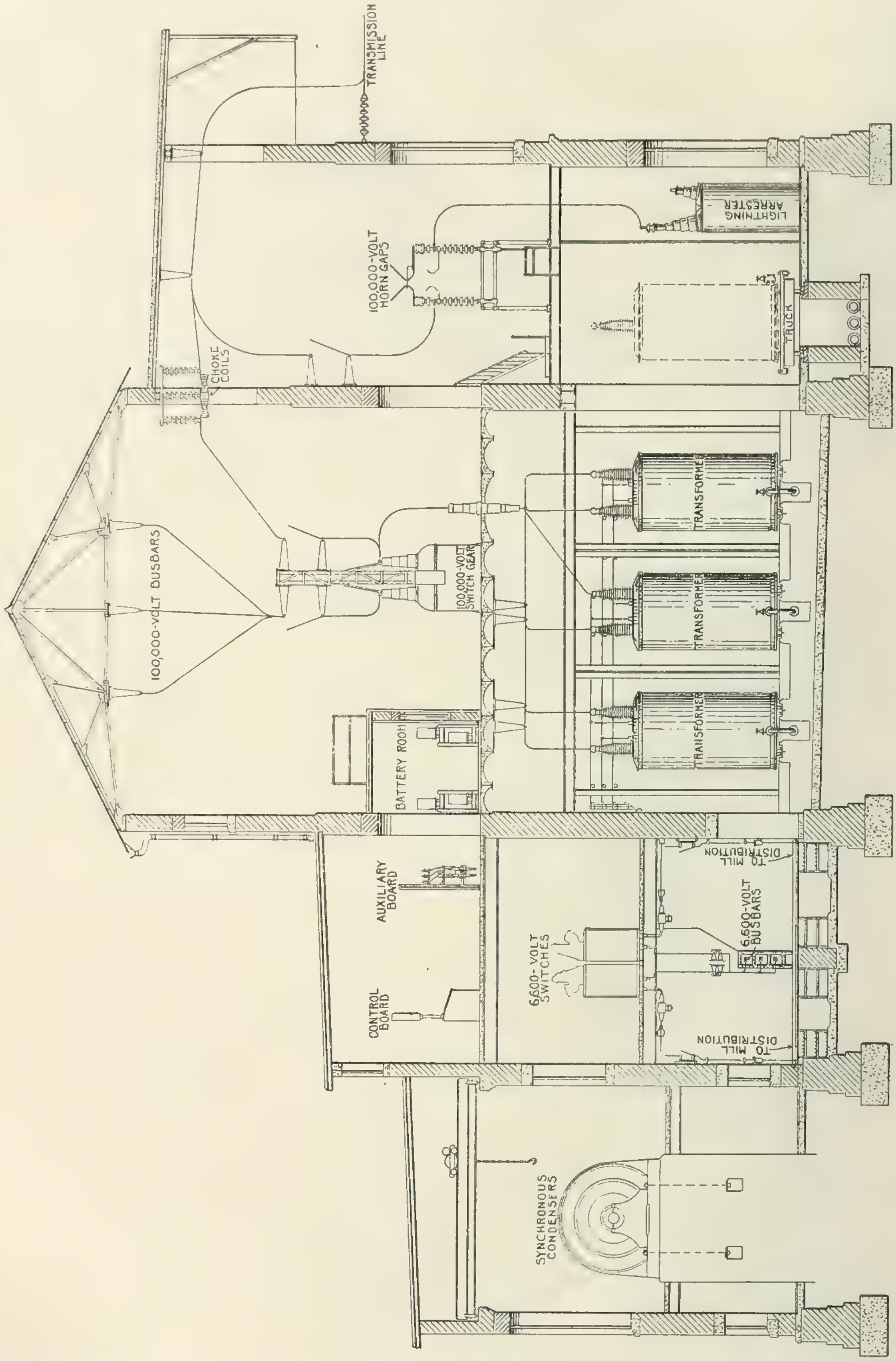
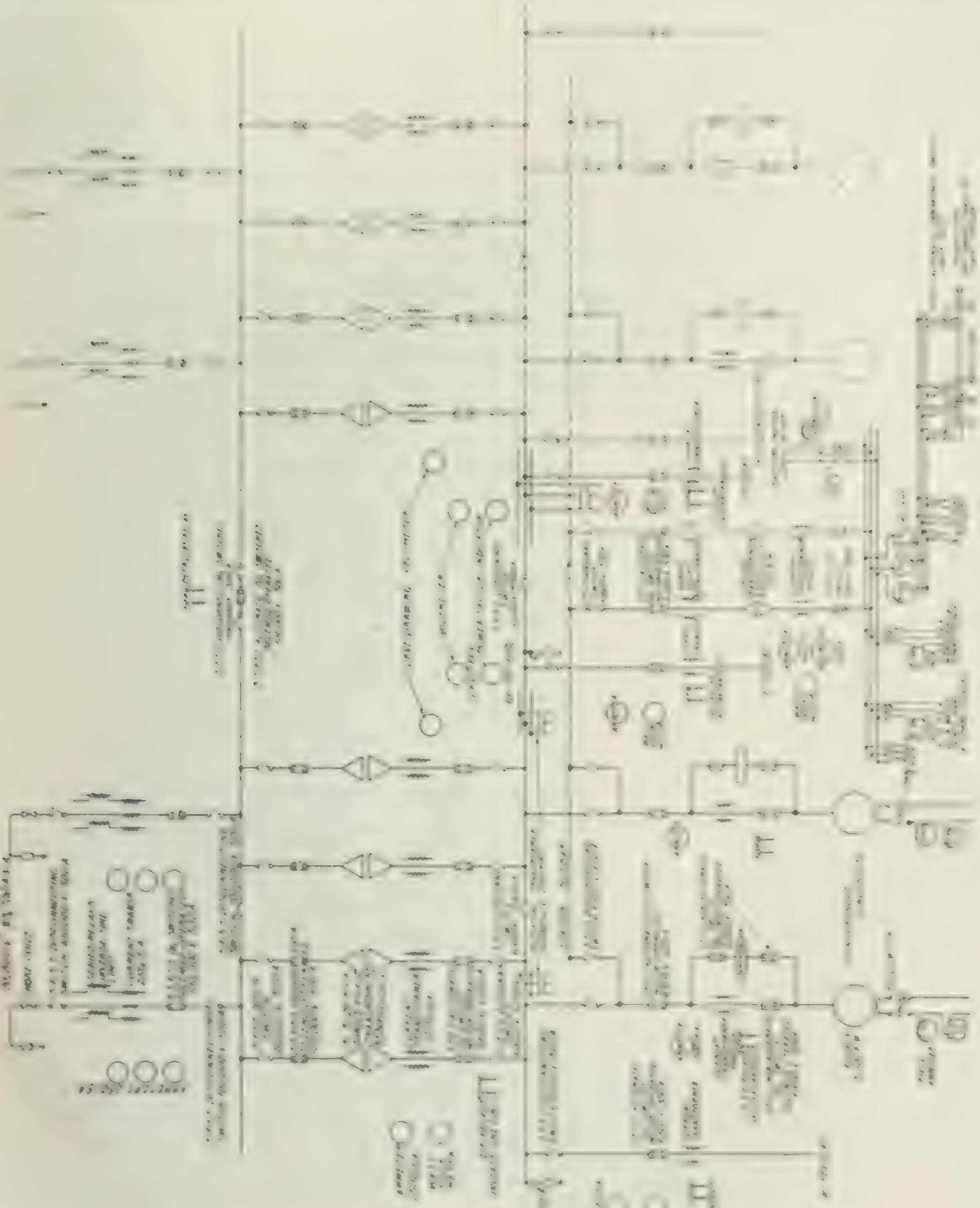


FIG. 14.—Elevation of Receiving Station.

The motors are rated at 3,000 k.v.a. full-load input with a temperature rise of 60 degrees F. for the armature, and 80 degrees F. for the field, the atmospheric temperature being taken at 110° F., and the motors are capable of running at 20 per cent overload for 10 hours without injury.



with an auxiliary board for the station power and lighting circuits.

The equipment in connection with the incoming lines, the high-tension side of the transformer banks, the high-tension busbar connections, and the lay-out is similar to the power-house equipment, except that the oil switches between the busbars and the transformer banks are automatically protected by the same relays as the low-tension oil switches.

The equipment on the low-tension side of the banks consists of triple-pole, motor-operated, automatic oil-switches in cell compartments, and current transformers and disconnecting switches, with similar equipments in the feeder circuits. In the former case the oil switches are provided with inverse time-limit, overload, secondary relays for automatic protection, and in the latter case with instantaneous, overload, secondary relays.

The low-tension 6,600-volt busbar system consists of copper bar, carried on insulators, in concrete compartments, sectionalized by means of disconnecting switches, whilst an auxiliary busbar is provided for the synchronous condensers and the station transformer. The plant is connected up on the low-tension side by varnished cambric-insulated, fireproof-treated cable.

Each phase of the motor-operated oil switches is contained in separate oil vessels, which can be readily removed from the cells.

The switchgear in the synchronous condenser circuits consists of disconnecting switches, a triple-pole, automatic, motor-operated oil switch, and a triple-pole, non-automatic, solenoid-operated oil switch; whilst current transformers are fixed in the main motor circuits, with triple-pole, non-automatic, solenoid-operated starting and magnetizing oil switches in the compensator circuit. All these switches are remote-controlled from the benchboard and also the motor-operated field rheostat and solenoid-operated exciter rheostat. The automatic oil switches are tripped by inverse time-limit, overload relays.

The station transformer bank is connected to the 6,600-volt busbar through a triple-pole, motor-operated oil switch with series, instantaneous, overload relays and disconnecting switches.

The benchboard consists of blue Vermont marble panels mounted on pipe supports, with grill work at the back, and fitted with instruments, control switches, indicating lamps, and a mimic busbar system for operating the two incoming lines, five transformer banks, 34 feeder circuits, synchronous condensers, and the station transformer.

The secondary relays are fixed on the back of the board. Calibrating and testing terminals are provided and also a swinging bracket carrying illuminated-dial instruments.

The control system is operated at 220 volts from a 60-ampere 8-hour battery, or from the 18 kw. charging set which also operates the series motors of the motor-operated oil switches.

The auxiliary switchboard controls the supply from three single-phase 42 k.v.a. 6,600/220-volt, 50-period station transformers. It is built of blue Vermont marble panels on pipe supports. It has a transformer panel, four double-feeder panels, a lighting panel and a battery and motor-generator panel. The busbars consist of copper bar carried on insulators on pipe supports at the back of the board. It is equipped with a triple-pole, automatic, hand-operated oil switch and current transformers in the transformer circuit, and triple-pole, lever switches and cartridge fuses in the power and lighting circuits.

The 6,600-volt busbars have aluminium-cell static dischargers, and an arrangement of earthed busbars, copper earth-plates, and connections similar to that at the power house is provided.

Dividing boxes on the wall of the 6,600-volt busbar room connect the varnished cambric, single-conductor feeder cables to the armoured 3-core cables which are run out of the building in an alley way to a cable chamber where they are connected to the feeder distribution-system.

Feeder System.

The feeder distribution-system from the receiving station to the mills is designed for a 6,600-volt 50-period 3-phase supply with an unearthed neutral. The cables are of the 3-core paper-insulated, lead-covered type, in standard sizes (viz. 0·1, 0·15, and 0·2 sq. in. section) and are laid on the solid system in bitumen in earthenware troughing in trenches 18 inches deep below the footway and 24 to 30 inches below the surface in side and main streets. They are designed for continuous operation at a current density of 1,050 amperes per square inch for the 0·2 sq. in. size, 1,240 amperes per square inch for the 0·15 sq. in. size, and 1,560 amperes per square inch for the 0·1 sq. in. size, with a reduction of 5 per cent in the carrying capacity when two, and 15 per cent when four cables are laid side by side. The mills are arranged in groups, each group having a feeder to each mill, with an emergency ring-feeder connecting up all the mills of the group.

Fig. 16 shows the grouping of the mills and the feeder distribution lay-out.

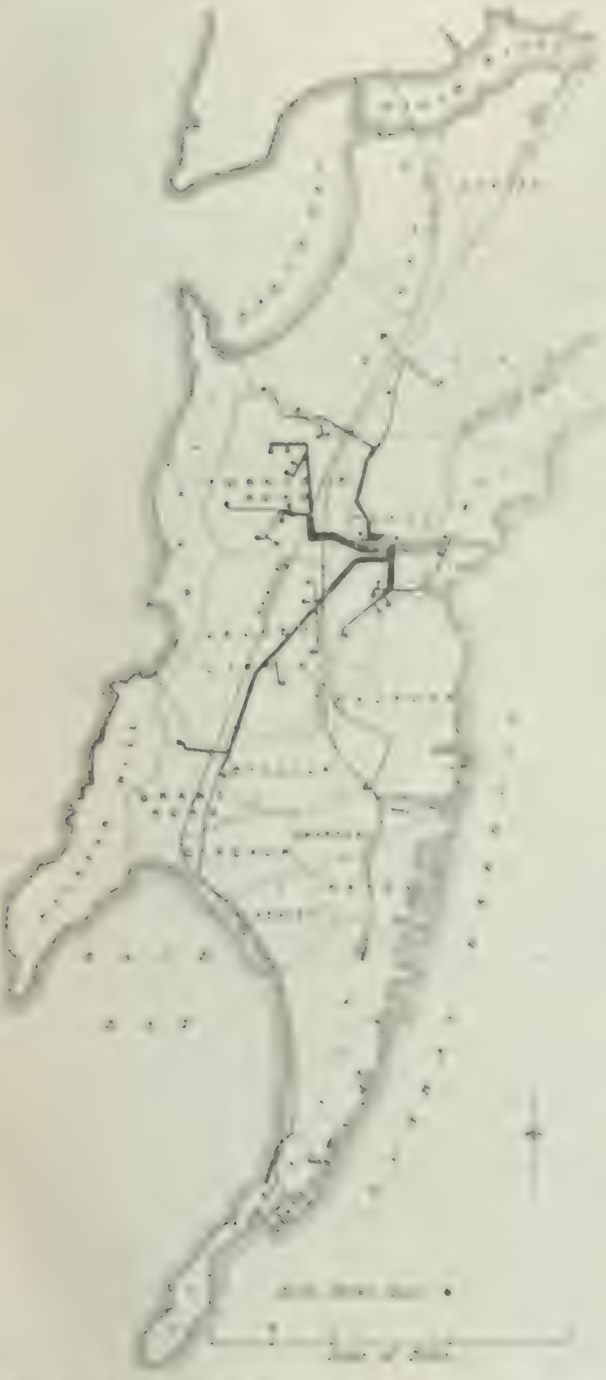
Mill Equipments.

The problem presented by the Bombay Mills was the conversion of mechanical to electrical drive utilizing the present shafting, the change being effected with as little interference as possible with the production of the mills. The problem was thoroughly investigated, and after due consideration group-driving with direct-coupled motors was adopted as being best suited to the requirements of the Bombay industry.

Standard speeds of 265, 290, and 365 r.p.m. were adopted.

The motors are of the slip-ring induction type, wound for 2,000 volts 3-phase, 50-periods, and provided with brush-lifting and short-circuiting gear, and are in standard sizes ranging from 30 to 500 horse-power. They are designed for full-load rating with a temperature rise of 70 degrees F. above air at 100° F., and for 50 per cent overload for half-an-hour without undue heating. The full-load efficiencies range from 87 to 92·5 per cent, and the full-load power factors from 0·74 to 0·84.

The starting switches are of the liquid type, the electrodes being operated through slow-motion gear and the motors being designed to start up against the full-load torque with a starting current not exceeding the full-load current. In the case of callender machines special starters are required in order to meet the conditions of the service.



Power-house and receiving-station transformers and switchgear	General Electric Co., New York.
Turbines and generators ...	Siemens Brothers Dynamo Works, Ltd.

The following are the principal members of the engineering staff :—

Engineer in charge of hydraulic section	R. B. Joyner, C.I.E.

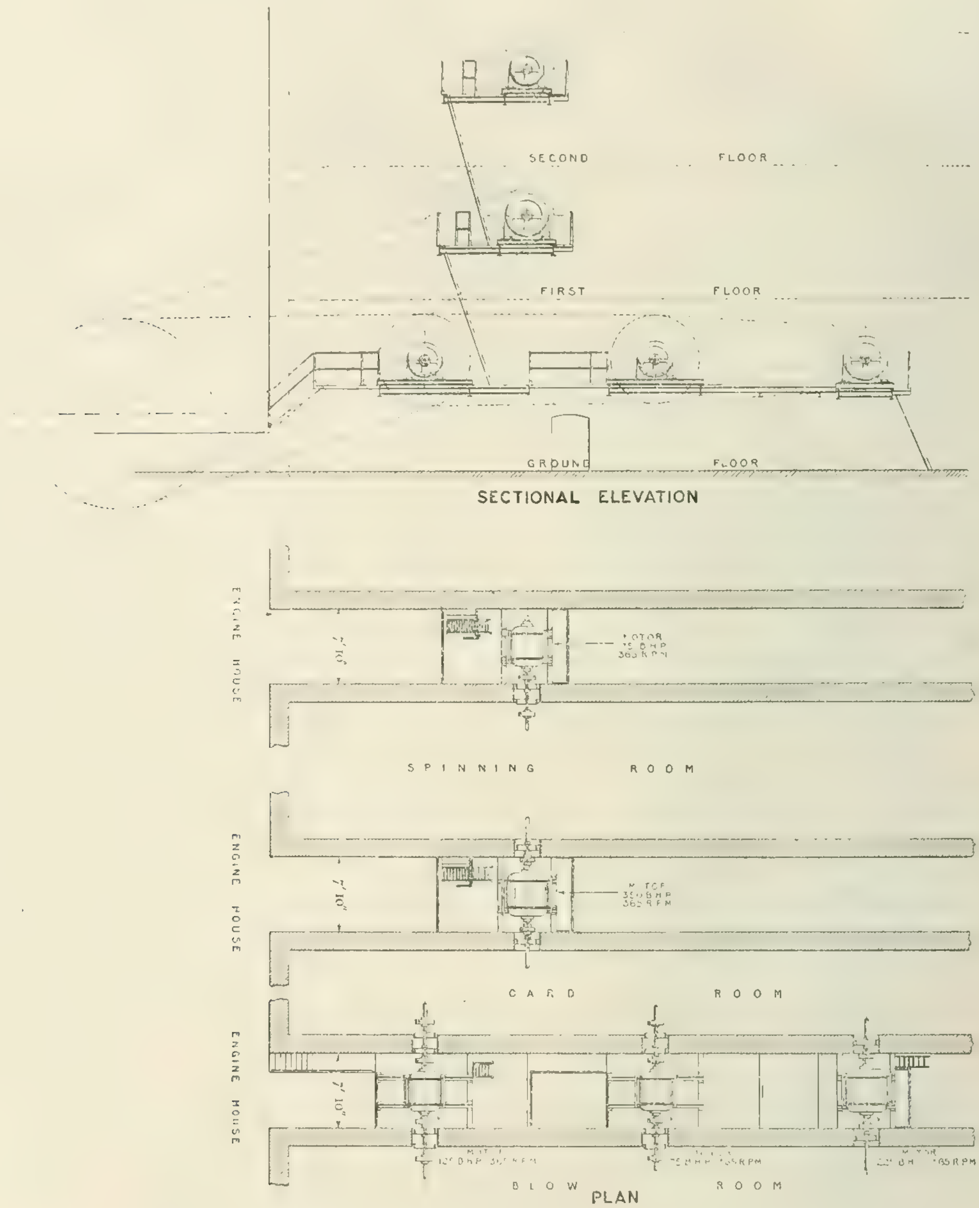


FIG. 17.—Sectional Elevation and Plan of Motors and Stagings.

Transmission towers and insulators	Bullers, Ltd.
Mill equipments	British Westinghouse Electric and Manufacturing Co., Ltd.
Street distribution system ...	Callenders Cable and Construction Co., Ltd.

Resident engineer on hydraulic works	B. D. Richards
Resident electrical engineer and general representative in India	H. P. Gibbs.
Chief of electrical staff ...	E. S. W. Moore.
Consulting engineer ...	A. Dickinson.

[illegible]

[illegible] volts has been used for so short a distance. It would be [illegible] the saving in copper bal[illegible] the author has used lime mortar for the reservoirs. On [illegible] voirs supplying water to Birmingham he explained to me that Portland cement, though more expensive, was infinitely stronger and much quicker in setting than lime [illegible] mention in his reply why he preferred lime mortar to [illegible] pressure, and also how corrosion is guarded against. In connection with the power house, I notice that the [illegible] mission lines. I should like to know why he did that. I am aware, as no doubt the author is, that one of the Niagara Companies has had considerable trouble with the [illegible] that special means have had to be taken to deal with the

[illegible] of this problem and on the way [illegible] cities of other countries, but would keep the city as far [illegible] which is one of the most wonderful [illegible] ments that has ever taken place in the E[illegible] in the world.

[illegible] proud. My only regret is that so much [illegible] come from Great Britain. Mr. Ham[illegible] a lower pressure been adopted for a [illegible] calls the line efficiency, and he gives the e[illegible]

Mr. Rider.

that he uses two separately-driven exciter sets. I should like to know why he has adopted separately-driven exciters in place of independent exciters upon each of the turbines, because he is in the position that if one of the exciters fails and the other one is not running, the whole station is shut down instead of only one unit. The arrangement of the governors of such large turbines is one of the most important things connected with the plant, but the author does not mention how the governors are driven. I have been responsible for a small hydro-electric plant in the Transvaal, transmitting over a distance of about 22 miles. We have turbines of the same general type but of a very much smaller size than those used by the author, and our experience is that the turbines are built by one firm and the governors usually by another firm. The governors are fixed upon a concrete foundation close to the turbines, and are generally belt-driven because the turbine maker will not go to the trouble of putting an extension to his bedplate and of using a mechanically-driven governor. Belt-driven governors are an abomination, and I wish water-turbine makers would learn, as engine makers learnt long ago, that their governors should be direct-driven for safety. In dealing again with the transmission system, I notice from page 705 that the author is using star-wound generators with the neutral not earthed, and delta-delta step-up transformers and delta-delta step-down transformers. He has apparently no earthing connection on any part of his system. I do not know what the climatic conditions are in the neighbourhood of Bombay, whether they suffer there from lightning or not, but it has been found on the Rand that earthing the system in several places has been essential in order to reduce the risks from lightning. I should like to know why the author deliberately leaves his generator neutral-point unearthed, why he uses delta-delta step-up and step-down transformers, why he does not have a neutral point on the low-tension distribution system, and why he does not earth it. He will understand that these questions are not being asked in a hypercritical spirit, but for the sake of getting a little more information which will be of considerable value to us. Both Fig. 14, which shows a cross-section of the receiving house, and Fig. 8, which shows a cross-section of the power house, give some indication of the arrangements which have been made for lightning protection, and I notice there is only one horn-gap arrester in series with an aluminium lightning arrester. Has the author had any experience of the operation of this arrangement, and has he found that one horn arrester is sufficient protection with a line of this nature, as on the Rand there are four or five horn arresters in series, and I do not think that any aluminium arresters are used at all? On page 704 in describing his switchgear arrangements the author tells us that the switches in the station are electrically operated at 220 volts from a small battery with a motor-generator, while the exciting pressure is 250 volts. Would not it have been better to have taken the operating system for switchgear from the exciting circuit, which is at a pressure only 30 volts higher, and to put the battery in parallel with the exciters? There would then be a stand-by for both services. The switchgear is evidently American made, and I notice that it has pipe supports. Has the author had any trouble with the use of pipe supports? The panels are made of very nice blue Vermont marble, and therefore they should have good supports, but I should like to know whether the author has found it necessary to adopt a proper angle steel framing, as, in my experience, pipe supports are not to be relied upon. The line as described in the paper is novel to me, because instead of being a single conductor, as is usual, it is a 7-strand wire. What reason had the author for adopting a 7-strand wire rather than a solid conductor, and does he expect any trouble due to corrosion of that wire, because it will have a larger surface and obviously interstices for moisture to enter which a solid wire has not? The insulators used are of the suspension type, and notwithstanding Mr. Hammond's remarks I think that is the correct type to adopt. The experience on the Rand with the Rand Mines Power Company's lines has been that no trouble has been caused by swinging, but I should rather have questioned whether six insulators in series would have been sufficient for a 100,000-volt line. On the Rand they are using six in series for only 80,000 volts, and on the little line which I mentioned before, 22 miles long, we had to put two in series for 20,000 volts in order to maintain the insulation, as one was not sufficient. We cannot of course always take things pro rata, but that allows one insulator for about every 10,000 volts; the author's factor is certainly very much higher than that. The paper falls short at the end in one most important matter; it gives no figures of either capital or operating costs, and I am sure we should all be glad if the author could give us those figures. It may be that the plant has not been working long enough for any reliable working costs to be obtained. We should, therefore, like to know the date when it was started. Then, last but not least, I should like to ask whether the author has had any troubles with his hydraulic or electrical plants. If he has, what are they?

Mr. Doelly.

Mr. E. DOELLY: I should like to refer to one point mentioned by the last speaker, namely, the method of driving the oil-pressure turbine governors. The governors described in the paper are belt-driven, the pendulum and oil pump each having its own separate drive, and the former being driven by a double belt. One of the chief parts of the governor is its oil pump, either of the tooth-wheel or piston type. My firm have several times applied a rigid drive, but in some cases this rigid drive—which was originally adopted at the special request of our clients—had to be replaced later by a belt drive owing to the shocks in the rigid transmission between the main shaft of the turbine and the governor pump-shaft. These shocks, although small, lead to trouble in the continuous running of the plant if the governors are rigidly driven, but are rendered quite harmless if a belt drive is adopted. The governors are fitted with automatic devices which shut down the turbine immediately in the event of either the belt driving the pendulum or the belt driving the oil pump coming off, thus doing away with any danger arising out of the application of belt drives.

Major-General Beresford-Lovett.

Major-General BERESFORD-LOVETT: The scheme described in the paper is as bold as it is important. It is the first hydro-electric project that has been financed in India on a purely commercial basis. Therein it differs from its predecessors, namely, the well-known Mysore project, which was followed soon after its completion by the Kashmir undertaking. Both of these projects were

[illegible] Bombay side for [illegible]

[illegible] extra supply. But that is not all. He has to reckon with [illegible]

[illegible] advisable it might be, from the contractor's point of view, [illegible] ng devices, it would be extremely unfair on the [illegible]

[illegible] information as to the amount [illegible]

[illegible] above the other. I believe [illegible]

[illegible] mentioned that Dr. Pearson preferred to use pin [illegible] saying that the pin insulators which Dr. Pea[illegible]

[illegible] Mr. Rider mentioned that the Victoria Fa[illegible]

[illegible] extent, [illegible]

Sir John McCall

of the Tasmanian schemes by the erection of a wall only 50 or 100 yards long. The first power scheme carried out in Tasmania, known as the Lake Margaret scheme, was carried out by the Mount Lyall copper mine; and to show the great value of that scheme, I may say that I have been informed by the manager of the mine that the cost of the smelting, so far as the power is concerned, will be reduced by 25 per cent, which is a most important consideration in connection with the work. Then we have what is known as the Great Lake scheme. The Government of the State gave certain private people the right to harness the waters of this great lake, which is situated some 3,800 feet above sea-level, and holds as much water as all the dams that we have heard about to-night. That was obtained by constructing the small amount of masonry at the outlet to which I have referred. It was secured for the purpose of working a zinc process, but it was put forward as a light and power scheme. Sufficient money was obtained in London to go on with the works, but not to complete them. The Government therefore took over the works, and are now completing the scheme. They paid off the debenture holders and allowed the Company sufficient money to erect works for the purposes of the first industry to be dealt with, which is to be a carbide works, and sufficient money also to experiment further in the zinc separation process. We are now looking forward to the hydro-electric works in Tasmania making that State probably the principal manufacturing State of the Australian Commonwealth, and we fully anticipate that what the author has claimed the Tata hydro-electric works will be to the cotton industry in India, the hydro-electric works of Tasmania will be to the woollen industry in that country. The Government are fortunate in having secured the author as consulting engineer in connection with the Great Lake scheme.

Dr. Railing.

Dr. A. H. RAILING: Apart from what has been called the boldness of the power generation and transmission, the feature of the scheme which has impressed me most is what I should call the diversity factor. We have heard such a lot about diversity factors of consumption that I should like to point out that here is a case which to my mind seems unique, and I confess it has made me change my opinions in quite a number of directions. We have here a scheme in which during the three monsoon months of the year sufficient power is accumulated to supply 88,000 horse-power for 12 months. The diversity factor under these circumstances is so very large that I do not know of a similar case in connection with any other water-power scheme. A similar scheme in England would be impracticable, because probably the capital outlay entailed in connection with the work would prevent it being a commercial success. I should like to know from the author what is the cost of labour in India. I assume that the low cost of Indian labour had a good deal to do with the practicability of the scheme. In that respect I disagree with Mr. Callender, because I think excavation work might be much cheaper in India than in this country in spite of the greater efficiency of English workmen. In connection with the pipe line illustrated on page 699, how are the pressure-rises dealt with? The pipe line is so very large that I should like to know whether special precautions have been taken in order to prevent a collapse of the pipe if anything went wrong. Next, it is said that the speed variation is about 12 per cent when load is suddenly thrown off the generators. If in addition to that there is the voltage regulation mentioned in the paper, I suppose that pressure-rises of something like 36 to 40 per cent of the normal voltage would result. Are any special surge-protection devices provided in the line in order to protect the machinery? I know that the author mentions spark-gaps later on, but it is not quite clear whether those spark-gaps are meant for static discharges or sudden rises of pressure. Then I should like to have some further information in connection with the temperature rise of the machinery. The author says that on the generators he specifies 60 degrees rise above air at 110° F. and 20 per cent overload for 10 hours without injury. I take it that that means roughly a 90 degrees rise, and therefore a temperature of about 200° F., which is of course permissible. On page 712, however, the author says that for the synchronous motors in the receiving station he allows 60 degrees rise for the armature and 80 degrees rise for the field coils. Allowing 80 degrees rise for the field coils with a 20 per cent overload will bring the temperature up to, I should say, about 210° F. measured, and therefore very probably to about 240° F. inside the field coils. I should therefore like to know from the author whether this 20 per cent overload is only used in case of emergency. I should like also to refer to the use of a stranded wire for the transmission line instead of a solid copper wire. I have not worked out the skin effect, but it would be interesting to know why the author adopted a stranded wire. I also made a note of the point on page 709 to which Mr. Rider referred. From the paper it would appear that the figure is 14·2 per cent, but that does not agree with the efficiency figure mentioned. We do not know what is the power factor of the transmission line, but perhaps the author could give us some idea of the power factor under certain load conditions. Of course it depends upon the load on the transformers, and for that reason we cannot work it out by considering merely the transmission line itself.

Mr. Sills.

Mr. G. F. SILLS: I should like to ask the author what difficulties were encountered in connection with obtaining the necessary right of way for the transmission line, especially if the line at any part was carried through a thickly-populated district. With reference to the water head in the turbine, it is hard to realize what a head of over 1,700 feet means. I have been through the large power houses at Niagara Falls, and in one station I was informed that the effective head was about 143 feet, although the Falls themselves are about 167 feet high. When it is considered that the Tata Company use a head more than 10 times as great as this, the great difficulties which had to be overcome by the engineers will be realized. Mr. Hammond raised the question of the adoption of a pressure of 100,000 volts for such a short line. I think I am right in saying that a line of about 45 to 50 miles long has been in operation at 100,000 volts in Germany for three years. The author showed a slide depicting some towers with their bases in the water. It is interesting to note in connection with the 110,000-volt scheme of the Hydro-electric Power Commission of Ontario, Canada, and with reference to the transmission line on the outskirts of Toronto, that the stepping-down station in Toronto was constructed, the transmission line erected, and everything was ready with the exception

taken into account to compensate for humidity in India is

experienced with the electrolytic lightning arresters,

and every time the electrolytic arresters were charged the

referred to

similar output could

plete, say five to ten

miles away would, however, have improved matters almost as effectively if the prevailing winds were considered in fixing the site. "Sentimental" either in the sense that non-technical subscribers to the scheme may have thought that they would obtain power for nothing, or that wealthy Natives may have been prepared to find money for utilizing what they considered one of the natural resources of their own country; whereas, for a more economical modern steam scheme, money would possibly not have been forthcoming locally. "Economic" in the sense that it may have been necessary or advisable to provide employment for hoards of unskilled natives. The hydro-electric scheme certainly would score under this heading, if no other overall economy is apparent from the paper. I venture to suggest that it would have been better to include some such reasons, or to justify the financial and engineering side more fully in presenting this paper before the Institution.

Mr. Molesworth. Mr. W. H. MOLESWORTH (*communicated*): Any information added to this valuable description of the Bombay hydro-electric installation will, I am sure, be much appreciated by members; for instance, working experience, the load factors of individual mills, the minimum daily and yearly average load factors of the load, obtained or expected. The scheme is designed for 88,000 horse-power; for four transmission circuits with conductors of over 1 inch diameter (each 7 strands of 0·095 square inch). To avoid corona losses during the monsoon such large stranded conductors are essential at 100,000 volts and 50 cycles per second. In view of the low-speed motors and generators, and the predominance of inductive reactance, a frequency of nearer 25 cycles is desirable. For only 43 miles of transmission line and only 21,000 kilowatts per circuit (*i.e.* one-third of 88,000 horse-power, assuming three circuits operating and one spare) a voltage of 80,000 appears ample. There are doubtless reasons for this high combination of voltage and frequency which are neither mentioned nor apparent, but the impression given is a very unnecessary expenditure in conductors simply to avoid corona losses consequent upon a mysterious combination of high voltage and high frequency.

Mr. Clayton. Mr. A. V. CLAYTON (*communicated*): I think it would be very interesting and instructive if the author could give the following figures of costs:—(1) The total capital outlay, and the cost of the entire system per effective horse-power available for sale; (2) the value of power in the district; (3) taking a fair rate of interest on the capital outlay, and an allowance for maintenance, depreciation, etc., how the cost of the hydraulic power compares with power that might be produced in large quantities from other sources in the district.

Mr. Dickinson. Mr. ALFRED DICKINSON (*in reply*): Mr. Hammond asks why a pressure of 100,000 volts was adopted for a line only 43 miles in length. The two principal reasons which fixed the adoption of this pressure were: (1) The greater immunity from the effects of lightning; and (2) that the line can at any future date be extended to longer distances without difficulty.

The chief reasons for the use of lime mortar in the construction of the dams were: (1) Cost; and (2) practically all the dams in India have thus far been built with lime mortar; Indian labour is therefore more accustomed to it than to cement mortar.

As to the method of making the circular joints on the pipe line, the 82 in. pipe is practically continuous. The pipes were delivered on to the site in 25 ft. lengths, the circular joints between the lengths being made and riveted on site. The 42 in. to 38 in. pipes have rolled bump joints double riveted, the joints between pipes being caulked inside and outside. The bump joint is very much like a ball and socket joint, and is made by swelling the ends of the pipes. In this way the internal heads of the rivets do not interfere with the flow of the water in the pipe. In reply to Mr. Hammond's observations about Pelton wheels, an impulse turbine is a form of Pelton wheel. My view is that the fewer the nozzles the less the difficulties are likely to be. Mr. Dickinson.

Suspension insulators.—The chief reasons for the use of this type of insulator were: (1) Greater flexibility and therefore less shock on the towers in the case of a conductor breaking, than is possible with the pin insulators: (2) easier transport and less trouble in erection; (3) cheaper in first cost and in maintenance; and (4) greater factor of safety.

Galvanized versus painted towers.—Specially painted, in preference to galvanized, towers were adopted because if the full stability of the towers is to be obtained they must be riveted on site; to rivet a galvanized tower destroys the galvanizing at the rivet holes, and therefore the benefit of galvanizing.

I have, in my reply to Mr. Hammond, dealt with Mr. Rider's question as to the adoption of a pressure of 100,000 volts.

As to Mr. Rider's point about the voltage on the transformers in relation to the pressure-drop on the line, mentioned on page 709, the voltage ratio of the transformers given is on open circuit, and the transformer pressure-drop has to be taken into account according to the load and power factors. There is therefore no discrepancy in the statement.

Each exciter is more than equal to the whole power-station requirements when extended. The separate exciter lends itself more readily to automatic voltage control on the generators. The exciters are reserved exclusively for generator excitation, and their circuits are deliberately kept apart from the pilot control and any other continuous-current supply; in fact, the exciter voltage is varied through wide limits, while the pilot control is at constant voltage. The scheme suggested by Mr. Rider was carefully considered and abandoned for these and other reasons. Mr. Doelly fully explained the point raised by Mr. Rider as to the working of the turbine governors.

One cannot secure all the advantage of star or delta arrangement, earthing or unearthed connection, without the accompanying disadvantages. The various combinations were very closely considered and a general unearthed system adopted. In the case of the generators, protection is obtained by teeing off each phase a circuit with triple-pole oil-damping resistances, on the earth side of which there are horn gaps between each phase, and then horn gaps in each phase, the outer horns being connected to earth.

The 100,000-volt single-phase transformer, as constructed, and the successful experience of the contractors with this apparatus, justified the adoption of the delta-delta connection. An earth on one line does not inevitably

[illegible]

[illegible] requirements, but the sleeve joint has proved satisfactory. Skin effect did not determine its adoption.

[illegible] above 200,000 volts.

[illegible] may be roughly ascertained by multiplying the turbine [illegible] incomplete, and it is at present impossible to give satis- [illegible]

[illegible] aluminium lightning arresters.

[illegible] red the fact that [illegible] more than 80,000 k.v.a. There are [illegible]

[illegible] Lovett as regards costs.

[illegible]

REPORT OF THE COUNCIL FOR PRESENTATION AT THE ANNUAL GENERAL MEETING OF 27 MAY, 1915.

At this, the Forty-third Annual General Meeting of The Institution of Electrical Engineers, the Council present to the members their Report for the year 1914–15.

Membership of the Institution.

The changes in the membership since the 1st May, 1914, are shown in the following table:—

	Hon. Mem.	Mem.	Assoc. Mem.	Assoc.	Grad.	Stud.	Totals.
Totals at 1st May, 1914	8	1,548	3,555	616	315	1,003	7,045
Additions during the year:—							
Elected	..	12	20	5	43	91	171
Reinstated	..	1	10	1	..	4	16
Transferred to	1	19	46	..	26	..	92
Total	1	32	76	6	69	95	279
Deductions during the year:—							
Deceased	1	19	22	5	1	6	54
Resigned	..	19	39	27	4	34	123
Lapsed (Estimated)	..	13	72	18	12	129	244
Transferred from	..	1	18	4	10	59	92
Total	1	52	151	54	27	228	513
Net Decrease ...							234
Totals at 1st May, 1915:—	8	1,528	3,480	568	357	870	6,811

In addition, 60 candidates for Associate Membership have been approved by the Council during the year for admission to that class on condition that they pass the Institution examination or otherwise satisfy the examination regulations. Of these, 1 is an Associate, 7 are Graduates, 11 Students, and 41 non-members.

Honours Conferred.

His Majesty the King has conferred the honour of Knighthood on the President, Sir John Snell, and the Honorary Grand Cross of the Victorian Order on Dr. Guglielmo Marconi (Member).

Military distinctions arising out of the war have been awarded to:

Brigadier-General A. M. Stuart, C.B., R.E. (Member), who was mentioned in despatches, and has received the Order of Companion of the Bath;

Commander E. G. Robinson, R.N. (Associate Member), who was promoted to the rank of Commander for distinguished service at the Dardanelles;

Second-Lieutenant G. W. Williamson, 3rd Manchester Regiment (Associate Member), who was awarded the Military Cross.

Honorary Member.

The Council have pleasure in recording the announcement made at the Ordinary Meeting of the 26th November last, that they had elected Professor Eric Gerard (Member), Director of the Institut Electrotechnique Montefiore, Liège, to be an Honorary Member of the Institution.

Members Deceased.

It is with deep regret that the Council have to record the deaths of three Past Presidents of the Institution, viz. Professor W. Grylls Adams, F.R.S., Mr. R. Kaye Gray, and Sir Joseph Wilson Swan, D.Sc., F.R.S.

Professor Adams, at the time of his death on the 10th April, 1915, was one of the senior surviving Past Presidents, having held the office of President in 1884, after serving successively as Member of Council and as Vice-President from the year 1876.

Mr. R. K. Gray served three periods of office as Member of Council (1894, 1898, and 1902–1903), and was twice a Vice-President (1895–1897, and 1899–1902). He served as President in 1903–1904. From 1899 to the time of his death on the 28th April, 1914, he was a Trustee of the Willans Premium Fund.

Sir Joseph Swan, who died on the 27th May, 1914, held the office of President in 1898. He served as a Member of Council in 1885 and 1896 and as a Vice-President in 1897. He was elected an Honorary Member in 1900.

The Council have also to deplore the loss of well-known members in Mr. Brackenbury Bayly (Chairman of the Cape Town Local Section, 1902–1903); Mr. Augustus Stroh (Member of Council, 1880–1889 and 1894–1896, Honorary Auditor, 1890–1897, and Honorary Auditor of the Benevolent Fund, 1890–1899), whose legacies to the Benevolent Fund and to the Building Fund are referred to later; Mr. A. B. Anderson, Member of Council, who was drowned in the *Empress of Ireland*; Mr. W. Grigor Taylor (Local Honorary Secretary for the Straits Settlements, 1902–1904); Colonel W. P. Brett, R.E. (Associate Member of Council, 1896 and 1897), and Dr. Henry Lewis Jones, the well-known authority on electrotherapeutics.

Seven members have been reported to have lost their lives in the service of their country, and their names, together with their military ranks and the names of their Corps, are set out in the following list:—

[illegible]

Joseph Alfred [illegible]	[illegible] Engineers, [illegible] R.N.D.	
Henry [illegible]	French Army	
Henry Herbert Stanley Moens	2nd Lieut. [illegible] R.E.	
[illegible]	[illegible]	
William [illegible]	[illegible] Engineers, [illegible]	
Guy [illegible]	[illegible]	Captain R.N.
Eric Western Wilson	[illegible]	2nd Lieut.

The [illegible] list of those who have died during the year is as follows:—

[illegible]

[illegible]

[illegible]

[illegible] William [illegible] Adams, F.R.S.
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
Samuel [illegible] Newington.
Charles [illegible]
[illegible]
[illegible]
[illegible] Patrick Robertson.
[illegible]
[illegible] R.N.
Alfred Richmond Sillar.
Frederick Smith.
Augustus Stroh.
William Grigor Taylor.

[illegible]

Alan Neville Banister.
[illegible]
[illegible] Walter [illegible] R.E.
Arthur [illegible] Broadbent.
Herbert N. Calvert.
Arthur Houle French.
[illegible]
William [illegible]
Hugh Vaughan Hart-Davis.
[illegible]
Herbert Robert Hudson.
[illegible]
Henry Herbert Stanley Moens.
Hugh Charles May.
[illegible]
[illegible] R.N.
[illegible]
Rigney Frederic Trotter.
Thomas Symonds Tuffield.
[illegible] Vignoles.
[illegible]
Poul A. von Wildenrath.

[illegible]

[illegible]
R. Heywood Claxton.
[illegible]
Henry Lewis Jones, M.D.
James Bonelle Willis.

Graduate.

William Reginald Radford.

[illegible]

[illegible]
[illegible]
[illegible]
[illegible]
William Walter Pullen.
Eric Western Wilson.

[illegible]

During the past twelve months 13 Ordinary Meetings and 18 [illegible] [illegible]

[illegible]

[illegible]

[illegible] Sections on account of the war deprived the [illegible] Newcastle [illegible]

[illegible]

[illegible]

[illegible]

[illegible] on Gyrostatics."

[illegible]

[illegible] Members of Council.

[illegible]

to Mr. C. J. Beaver, for his paper, "Cables."

[illegible]

[illegible]

[illegible]

[illegible] tective Swit[illegible]

[illegible]

[illegible] Machinery.

[illegible]

[illegible] Mining."

An Extra Premium, value £10,

to Mr. W. M. Selvey, for his paper, "Power Plant Testing."

An Extra Premium, value £5,

to Mr. N. Shuttleworth, for his paper, "Polyphase Commutator Machines and their Application."

Students' Premiums.

A Students' Premium, value £10,

to Mr. H. Hobson, for his paper, "The Utilization of Waste Heat for the Generation of Electrical Energy."

A Students' Premium, value £5,

to Mr. A. Arnold, for his paper, "Modern Power House Condensing Plant."

A Students' Premium, value £5,

to Mr. H. S. Marquand, for his paper, "Some Notes on Modern Methods of Electric Welding and Their Application."

Scholarships.

The Council have awarded two Salomons Scholarships of the value of £50 each, one to Mr. Leonard M. Barlow, of the City and Guilds of London Technical College, Finsbury, and one to Mr. Claude Douglas Farmer, of the City and Guilds of London (Engineering) College; and one David Hughes Scholarship of the value of £50 to Mr. Percy Davis Morgan, of King's College, London.

Students' Sections.

Eight meetings of the Students' Section have been held, at which papers were read and discussed. At the opening meeting an address to the Students was delivered by Mr. C. H. Merz, Vice-President, on "Power Supply and Recent Developments in connection therewith."

The Manchester and Newcastle Students' Sections have held 9 and 4 meetings respectively.

No meetings have been held by the Scottish Students' Section.

Meetings of Other Societies.

During the year, 22 Societies have held meetings at the Institution, as follows:—

	No. of meetings
The Associated Municipal Electrical Engineers of Greater London	14
The Electrical Trades' Benevolent Institution	6
The Incorporated Municipal Electrical Association	25
The Institution of Post Office Electrical Engineers	10
The Institution of Railway Signal Engineers	5
Junior Institution of Engineers	8
Post Office Telephone and Telegraph Society	7
The Röntgen Society	7
The Society of Engineers	7
The University of London Board of Studies in Electrical Engineering	4
The Wireless Society of London	7
Eleven other Societies	20
	120

"Science Abstracts."

The volumes for 1914 contain about the same amount of matter as in 1913, the matter for the "Physics" Section showing a slight increase, which is balanced by a small decrease in the "Electrical Engineering" Section.

The Council have recently (*Journal*, vol. 53, p. 348) directed the attention of members to the utility of the publication as a record of scientific progress and as a work of reference, and have urged upon the members the desirability of their becoming regular subscribers.

Wiring Rules.

A revision of the Wiring Rules is in progress, in connection with which 18 meetings of the Wiring Rules Committee have up to the present been held.

Model General Conditions for Contracts.

Of the revised Model Conditions approved by the Council and published on the 1st May, 1914, over 2500 copies have already been disposed of. There is evidence that these Conditions are being largely adopted by consulting engineers and others.

Research.

The Research Committee have made further progress with the work in hand in connection with (*a*) Magnet Steels, (*b*) the Heating of Buried Cables, and the (*c*) Properties of Insulating Oils. An investigation into the Maximum Current Densities which can safely be allowed on conductors of various cross-sectional areas is also under the consideration of the Committee. During the past year two Interim Reports (*Journal*, vol. 52, p. 779, and vol. 53, p. 328) on the Heating of Buried Cables, and one Interim Report (*Journal*, vol. 53, p. 146) on the Properties of Insulating Oils have been published.

Sectional Committees.

There are at present five Sectional Committees which were appointed by the Council last year, namely:—

(1) Lighting and Power.
(2) Electric Traction (including Railways, Tramways, and other Means of Transport).
(3) Telegraphs and Telephones (including Radio-Telegraphy and Railway Signalling).
(4) Electro-Chemistry and Electro-Metallurgy.
(5) Electricity in Mines.

These Committees have held a number of meetings and have been engaged in obtaining papers on subjects connected with the branches of electrical engineering which they represent.

National Service.

A few days after the outbreak of the war a special meeting of the Council was held at which it was agreed as follows:—

(*a*) That the Institution take action to assist the authorities.
(*b*) To offer to the War Office free of charge and for immediate occupation, the available space in the Institution building.

(c) To place the organisation of the Institution at the disposal of the Admiralty and of the War Office to select from its members men trained in electrical engineering for any purpose the Admiralty or the War Office may indicate.

(d) To take steps to assist in filling the vacancies occurring in the Public Services, Electric Power Stations, Tramways, etc.

(e) To appoint a National Service Committee to deal with the above matters and with authority to take such further steps as they may deem advisable to assist the organisation of the Institution in connection with the war or any emergency that may arise therefrom.

Under the authority given by the Council the National Service Committee immediately issued a circular form with reply form inviting members to place their services at the disposal of the Institution in connection with the Army, the Navy, Public Services, etc., and in response to this circular [illegible] offers of service from members and others [illegible] were received, among whom were included many [illegible] for service in the Army or the Navy.

The offers of service received were placed by the Council at the disposal of the following Government Departments:—The Admiralty, the War Office, the Post Office, the Colonial Office, the Home Office, the Scottish Office, the Office of Works, the Local Government Board, the Board of Trade, the Central Labour Exchange, the Royal Flying Corps, and the Crown Agents for the Colonies.

The Committee also sent a circular to the Chief Engineers of the Electricity Supply Undertakings in the United Kingdom informing them of:—

(a) the offers of service received by the Council and placing them at the disposal of the various Undertakings;

(b) the precautions taken in London for the protection of the Electric Power Stations and for the security of the public supply of electricity.

A number of vacancies in power stations were filled by this means, but it soon became evident that there were practically no supply station men unemployed.

Royal Naval Division.

Early in September Mr. A. P. Trotter brought before the Council a scheme for the formation of one or more infantry battalions consisting exclusively of members of professional bodies, but before the proposal had been discussed in detail intimation was received from the Admiralty that about [illegible] engineers would be required for the Engineer Units of the Royal Naval Division, the formation of which had recently been sanctioned by the Admiralty, and it was thereupon agreed that in conjunction with the Institutions of Civil and Mechanical Engineers circulars should be sent immediately to all the members inviting applications to join the new Units and that a special Recruiting Office for this purpose should be opened in the Institution's vacant rooms at No. 2 Savoy Hill.

The Council also decided that in the meantime no further steps should be taken in regard to the formation of the infantry battalions mentioned above.

The response from members of the three Institutions was most satisfactory and the applicants were interviewed by a Committee of Selection consisting of [illegible], Mr. W. Duddell, F.R.S., [illegible], and Mr. A. P. Trotter, together with representatives of the Councils of the Institutions of Civil and Mechanical Engineers. [illegible] up to the full complement.

The medical examination of the recruits was carried out at the Institution by two Naval Surgeons appointed by the Admiralty, and the recruits were attested [illegible] by [illegible] and Mr. Edward [illegible], Justices of the Peace, [illegible] & Co., the Institution's Bankers.

Institution Rooms.

Since the outbreak of the war the rooms of the Institution on the first floor have been continuously in the occupation of Departments of the War Office and of the Admiralty, free of rent.

Commissions in the Royal Garrison Artillery and Royal Engineers.

At the end of October the President received a communication from [illegible], of the War Office, asking him to nominate young electrical engineers for temporary commissions in the Royal Garrison Artillery.

The President issued a circular to the Members, M.I.E.E., of the Institution inviting them to recommend suitable candidates. A large number of candidates were interviewed by the President, assisted by Mr. W. Duddell, and eventually a selected number were recommended for and obtained commissions in the Royal Garrison Artillery.

The President has also nominated some of the members for special temporary commissions in the Royal Engineers.

Members on Naval or Military Service.

From returns supplied by members it appears that there are at present some 928 members serving in the Navy or the Army, viz.:—

[illegible] Members.
[illegible] Associate Members.
[illegible] Associates.
[illegible] Graduates.
[illegible] Students.

[illegible]

ENGINEERS' VOLUNTEER CORPS.

The Council received during [illegible] a letter from General Sir O'Moore Creagh, V.C., Military Adviser to the Central Association of Volunteer Training Corps, inviting the Council's co-operation in the formation of an Engineers' Volunteer Corps affiliated to the Central Association.

The Council accordingly issued in March a circular to the members residing in the London district, and replies have been received from some 150 expressing their willingness to join such a Corps if formed. These offers have been communicated to the Central Association and the matter is still under consideration.

German Trade.

Soon after the outbreak of the war a Committee was appointed by the Council to keep in touch with the British Electrical and Allied Manufacturers' Association in regard to the question of securing for British manufacturers the trade hitherto done by Germany and Austria-Hungary. A number of meetings of this Committee were held, at which representatives of the Manufacturers' Association were present, and the position was very fully discussed.

Eventually after several suggestions had been considered the Committee came to the conclusion, with the concurrence of the Manufacturers' representatives, that the continuance and expansion of British trade after the war will mainly depend on economic principles and on the commercial industry and initiative of British manufacturers, and that no useful action on the part of the Institution appeared to be possible.

At first the Committee were in favour of holding a meeting for the purpose of discussing a paper on certain aspects of the competition of foreign countries, but after consideration the Manufacturers' Association were of opinion that the result likely to be obtained would not justify such a meeting being held, and at their request the idea was abandoned.

The Committee referred to above still remains in being for the purpose of advising the Council in regard to any questions which may arise in the future.

Periods for Repayment of Municipal Loans.

Several meetings have been held of the Committee appointed by the Council last year to consider the question of the periods of repayment allowed by the Local Government Board for loans to municipal authorities for the purchase of electrical plant. Although the terms of reference were intended to embrace all kinds of such plant, the replies received from certain Associations representative of different sections of the electrical industry, who had been asked for their views, made it evident that on the whole the only alterations desired were in regard to cables and batteries.

Enquiries were directed by the Committee to some 40 municipal supply undertakings for data as to the lives of cables laid down in various ways, the causes of their deterioration, and the residual value of old cables compared with the original cost. Opinions were also sought as to the desirability not only of extending the periods of repayment, but also of differentiating them according to the method of laying.

From the replies received there appeared to be a consensus of opinion that cables possessed longer lives than those which were assumed in fixing the present loan periods, and the Committee concluded that good grounds existed for approaching the Local Government Board to sanction a period of 30 years in the case of underground cables, provided they are substantially constructed and laid with due regard to the nature of the soil.

It seemed desirable also to treat substantially constructed conduits separately from cables, and to urge the adoption of a period of 60 years for such conduits.

In view of the great improvements in batteries which have taken place in recent years, the Committee recommended that the repayment period for these should be extended to 15 years, in cases where the sanctioning authority was satisfied that adequate provision had been made for the proper maintenance of the batteries.

In regard to reinforced concrete the Committee recommended an extension of the period to 30 years, so as to conform with that allowed by the London County Council.

The Council will in due course make representations to the Local Government Board on the lines indicated above.

Smoke Abatement.

Towards the end of last session the Council received a letter from the Local Government Board Departmental Committee on Smoke Abatement inviting the Institution to give evidence. The Council accordingly appointed a Committee for the purpose of preparing and submitting to the Council the draft of the evidence to be given before the Departmental Committee, but the Council having since been informed by the Departmental Committee that in view of the war the Committee had adjourned its meetings *sine die*, the matter is for the present held over.

Legacies to the Institution.

The Council have to record the receipt of a sum of £500 in payment of legacies of £250 each to the Building and Benevolent Funds of the Institution made by the late Mr. Augustus Stroh, to whose executors the cordial thanks of the members have been conveyed for this mark of attention to the interests of the Institution.

Benevolent Fund.

The Committee of Management of the Benevolent Fund of the Institution report that on the 31st December, 1914, the Capital Account of the Fund stood at £4,642 3s. The donations and subscriptions to the Fund in 1914 amounted to £179 19s.

At the end of March, 1915, in view of the cases then before the Committee and of other cases likely to occur in the near future, the President was authorized by the Council to make an appeal to the members of all classes of the Institution (except Students) for subscriptions and donations to the Fund. The result of this appeal was as follows :—

	£	s.	d.
35 Annual Subscriptions	41	1	6
38 Donations	276	9	6

The Council desire to acknowledge their indebtedness to the generosity of the donors and subscribers who have supported the Fund, but in view of the inadequacy of this result, the Council venture once more to urge upon the members the pressing need for a more generous response to the President's appeal, and desire to add that, apart from donations, the Committee of Management will be grateful for annual subscriptions even of quite small amounts.

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]

[illegible] leaving to the credit of the Fund £5,409 19s.

[illegible]

[illegible] Subscriptions, etc.	[illegible]	[illegible]	[illegible]
[illegible] Revenue	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]

[illegible] Taking the [illegible] Street property and the Investments at cost, and the Institution Building and Lease, the Library and Furniture, etc., at the values standing in the books after writing off depreciation—

	£	s.	d.
[illegible]	114,929	3	5
[illegible]	[illegible]	[illegible]	[illegible]
leaving a margin to the good of ...	[illegible]	[illegible]	[illegible]

which is made up as follows :—

	£	s.	d.
Building Fund ...	[illegible]	[illegible]	[illegible]
Life Compositions Fund...	5,409	19	0
[illegible] Fund	[illegible]	[illegible]	[illegible]
Foreign Visit Fund ...	92	14	2
Subscriptions received in advance ...	[illegible]	[illegible]	[illegible]
General Fund ...	[illegible]	[illegible]	[illegible]

This margin set against the margin to the good in 1913 of ...	[illegible]	[illegible]	[illegible]
shows an improvement for 1914 of ...	[illegible]	[illegible]	[illegible]

LIBRARY

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]
Ronalds Library ...		[illegible]
		[illegible]

[illegible] last, and after inspecting the books stated that in their [illegible]

[illegible] Library have been made.

[illegible]

[illegible]

[illegible]	[illegible]
[illegible]	[illegible]
A [illegible] of the magnetic storm recorded at [illegible]	[illegible]
A delineation of lines of force by means of iron filings, prepared by [illegible]	[illegible]
Early electric lamps, lamp-holders, [illegible]	A. H. Allen
An early switch, a cut-out, and mica [illegible]	[illegible]

APPENDIX TO REPORT.

TRANSACTIONS, PROCEEDINGS, ETC., RECEIVED BY THE INSTITUTION.

BRITISH

[illegible]

BRITISH—*continued.*

Institute of Marine Engineers, Transactions.
Institute of Metals, Journal.
Institution of Civil Engineers, Proceedings.
Institution of Engineers and Shipbuilders in Scotland, Transactions.
Institution of Mechanical Engineers, Journal.
Institution of Mining and Metallurgy, Transactions and Bulletin.
Institution of Naval Architects, Transactions.
Institution of Post Office Electrical Engineers, Papers.
Institution of Railway Signal Engineers, Proceedings.
Iron and Steel Institute, Journal and Carnegie Memoirs.
Junior Institution of Engineers, Journal.
Liverpool Corporation Tramways, Annual Report.
Liverpool Engineering Society, Proceedings.
Manchester Literary and Philosophical Society, Memoirs and Proceedings.
Municipal School of Technology, Manchester, Journal.
National Physical Laboratory, Reports and Collected Researches.
North East Coast Institution of Engineers and Shipbuilders, Transactions.
North of England Institute of Mining and Mechanical Engineers, Transactions.
Physical Society, Proceedings.
Röntgen Society, Journal.
Royal Dublin Society, Scientific and Economic Proceedings.
Royal Institution, Proceedings.
Royal Meteorological Society, Quarterly Journal.
Royal Society, Philosophical Transactions and Proceedings.
Royal Society of Arts, Journal.
Royal Society of Edinburgh, Transactions and Proceedings.
Royal United Service Institution, Journal.
Rugby Engineering Society, Proceedings.
Society of Chemical Industry, Journal.
Society of Engineers, Transactions.
South Wales Institute of Engineers, Proceedings.
Surveyors' Institution, Transactions and Professional Notes.
Tramways and Light Railways' Association, Journal.

COLONIAL.

Australian Official Journal of Patents.
Canada, Department of Mines, Mines Branch, Reports.
Canadian Society of Civil Engineers, Transactions.
Engineering Association of New South Wales, Proceedings.
Engineering Society of Toronto, Transactions.
Indian Telegraph Department, Administration Reports.
Royal Society of Victoria, Proceedings.
South African Institute of Electrical Engineers, Transactions.
South Australia, Meteorological Observation Reports.
Western Australian Institution of Engineers, Proceedings.

AMERICAN (UNITED STATES).

American Academy of Arts and Sciences, Proceedings.
American Electrochemical Society, Transactions.
American Institute of Electrical Engineers, Transactions and Proceedings.
American Institute of Mining Engineers, Transactions.
American Philosophical Society, Proceedings.
American Society of Civil Engineers, Proceedings.
American Society of Mechanical Engineers, Journal.
Bureau of Standards, Washington, Bulletin.
Engineers' Club of Philadelphia, Proceedings.
Franklin Institute, Journal.
Illuminating Engineering Society, N.Y., Transactions.
Institute of Radio Engineers, Proceedings.
National Electric Light Association, Transactions.
Smithsonian Institution, Reports.
U.S. Official Patent Gazette.
U.S. Ordnance Report.
Western Society of Engineers, Journal.

ARGENTINE.

Asociaciòn Argentina de Electro Técnicos, Boletín.
Centro Estudiantes de Ingenieria, Revista.

AUSTRIAN.

Kaiserliche Akademie der Wissenschaften, Wien, Sitzungsberichte.

BELGIAN.

Association des Ingénieurs Électriciens sortis de l'Institut Électrotechnique Montefiore, Bulletin.
Société Belge d'Électriciens, Bulletin.

DUTCH.

Koninklijk Institut van Ingenieurs, Tijdschrift.
Koninklijke Akademie van Wetenschappen, Amsterdam, Proceedings.

FRENCH.

Académie des Sciences, Comptes Rendus Hebdomadaires des Séances.
Bureau des Longitudes, Annuaire.
Société des Anciens Élèves des Écoles Nationales d'Arts et Métiers, Bulletin Technologique.
Société des Ingénieurs Civils, Mémoires.
Société Française de Physique, Procès-verbaux, etc.
Société Internationale des Électriciens, Bulletin.
Société Scientifique Industrielle de Marseille, Bulletin.

GERMAN.

Schiffbautechnische Gesellschaft, Jahrbuch.
Verein Deutscher Ingenieure, Zeitschrift.
Verein zur Beförderung des Gewerbfleisses, Verhandlungen.

ITALIAN.

Associazione Elettrotecnica Italiana, Elettrotecnica.
Reale Accademia dei Lincei, Atti e Memorie.

JAPANESE.

College of Engineering, Kyoto, Memoirs.
College of Science, Kyoto, Memoirs.

SWEDISH.

K. Svenska Vetenskaps-Akademien, Arkiv för Matematik, etc.

SWISS.

Schweiz. Elektrotechnischer Verein, Bulletin.

LIST OF PERIODICALS RECEIVED BY THE INSTITUTION.

BRITISH.

A. E. G. Journal.
Beama Journal.
Cassier's Engineering Magazine.
Central.
Colliery Guardian.
Electric Railway and Tramway Journal.
Electric Vehicle.
Electrical Engineering.

BRITISH

[illegible]

COLONIAL

[illegible]

AMERICAN (UNITED STATES).

[illegible]

AUSTRIAN

[illegible]

DANISH

[illegible]

DUTCH

[illegible]

FRENCH

[illegible]
Houille Blanche.
Industrie Electrique.
[illegible]

GERMAN

[illegible]

ITALIAN

[illegible]

SWEDISH

Svensk Export.

SWISS.

[illegible]

THE INSTITUTION OF ELECTRICAL ENGINEERS.

REVENUE ACCOUNT FOR THE YEAR ENDED 31ST DECEMBER, 1914.

Dr. EXPENDITURE.

	£ s. d.	£ s. d.
To MANAGEMENT :—		
Salaries and Wages (including Staff Provident Scheme)	3,830 5 3	
National Insurance	14 1 6	
Accountants' Fees	21 0 0	
Printing	306 17 2	
Stationery and Office Requisites	179 11 8	
Addressing Machine Plates	19 16 2	
Postage of Correspondence and Notices	288 4 3	
Telephone	48 9 0	
Travelling Expenses	17 5 10	
Bank Charges	6 5 2	
		4,731 16 0
„ INSTITUTION BUILDING :—		
Ground Rent	2,201 0 0	
Rates and Taxes	1,872 17 7	
Light and Power	40 12 10	
Firing	273 17 3	
Insurance	100 19 10	
Reserve for Repairs	400 0 0	
Household Requisites and Cleaning	109 8 8	
		4,998 16 2
„ INTEREST ON MORTGAGES		1,462 9 3
„ FURNITURE AND FITTINGS (Repairs and Renewals)		42 14 8
„ JOURNAL :—		
Printing	1,451 16 3	
Postage	728 4 10	
Wrappers and Envelopes	83 4 7	
	2,263 5 8	
Less Sales	451 0 6	
		1,812 5 2
„ LIBRARY (Repairs to old Bindings)		116 4 5
„ LENDING LIBRARY (Books, Printing, Postage, etc.)		164 3 1
Carried Forward		£13,328 8 9

INCOME. **Cr.**

	£ s. d.	£ s. d.
By SUBSCRIPTIONS		15,454 9 11
„ ENTRANCE FEES		407 7 0
„ BUILDING FUND :—		
Donations and Subscriptions	31 8 0	
Surplus from Vellum Diplomas	10 10 0	
		41 18 0
„ DIVIDENDS ON INVESTMENTS		368 15 4
„ INTEREST		16 4 9
„ WIRING RULES		26 11 11
„ MODEL GENERAL CONDITIONS		27 8 11
„ INSTITUTION BUILDING :—		
Rent from Tenants		2,255 10 0
„ TOTHILL STREET PROPERTY :—		
Rents from Tenants	709 2 0	
Less Ground Rent, Repairs, Alterations, Rates, Taxes, etc.	585 19 0	
		123 3 0
Carried Forward		£18,721 8 10

REVENUE ACCOUNT—*continued.*

Dr. EXPENDITURE—*continued.*	£ s. d.	£ s. d.
Brought Forward		[illegible] 8 9
To National Service (Officers Royal Naval Division, etc.)		157 4 2
" Examinations		17 1 6
" Science Abstracts—		
Science Abstracting, Printing, Postage, etc.	1,844 9 1	
Less Subscriptions, Sales, and Advertisements	1,398 1 10	
		[illegible] 7 3
" Meetings—		
Advance Proofs	42 1 3	
Reporting	87 15 0	
Honorarium to Kelvin Lecturer	25 0 0	
Refreshments, Attendance, etc.	78 14 8	
		233 10 11
" Local Sections—		
Money Grants	781 3 9	
Travelling Expenses	180 1 4	
		961 5 1
" Premiums		164 8 6
" British Electrotechnical Committee		34 3 3
" Engineering Committee		190 1 7
" International Illumination Commission		[illegible]
" Conversazione		[illegible]
" Annual Dinner		[illegible]
" Legal Expenses		[illegible]
" Miscellaneous Expenses		[illegible]
		[illegible]
" Amounts Transferred to—		
Permanent Fund (Obligation, represented by Transferred Life Members' Fund)—		
(Donations, Subscriptions, etc. [illegible]) £[illegible]		
Contribution out of Revenue [illegible]		
	[illegible]	
Sinking Fund (Provision for Redemption of Cost of Building and Lease)	[illegible]	
General Fund—		
Expenditure—		
Books and Binding for Library	[illegible]	
Furniture and Fittings	[illegible]	
Balance being unexpended Revenue for the year 1914	[illegible]	
		[illegible]
		£[illegible]

INCOME—*continued.* Cr.	£ s. d.
Brought Forward	[illegible]
	£[illegible]

BALANCE SHEET, 31ST DECEMBER, 1914.

Dr. LIABILITIES.

	£ s. d.	£ s. d.
To BUILDING FUND :—		
Balance at 1st January, 1914	42,495 14 11	
Donations, Subscriptions, etc.	41 18 0	
Contribution out of Revenue	607 17 11	
		43,205 10 10
„ ECONOMIC LIFE ASSURANCE SOCIETY :—		
On Mortgage of Institution Building (1909) ...	26,000 0 0	
Since repaid	3,268 9 0	
	22,731 11 0	
On Mortgage of Tothill Street Buildings and Site (1910)	11,500 0 0	
		34,231 11 0
„ LIFE COMPOSITIONS FUND :—		
Balance at 1st January, 1914	5,506 19 0	
Less Life Compositions of Deceased Members transferred to General Fund	97 0 0	
		5,409 19 0
„ KELVIN LECTURE FUND		862 10 10
„ TRUST FUNDS CAPITAL ACCOUNTS :—		
Salomons Scholarship	2,126 19 3	
David Hughes Scholarship	2,000 0 0	
Wilde Benevolent Fund	1,846 4 6	
		5,973 3 9
„ TRUST FUNDS INCOME ACCOUNTS :—		
Balances unexpended :—		
Salomons Scholarship	18 16 4	
David Hughes Scholarship	30 12 6	
Wilde Benevolent Fund	21 5 5	
		70 14 3
Invested Income (Wilde Benevolent Fund)		345 14 8
„ FOREIGN VISIT FUND		92 14 2
„ SUNDRY CREDITORS		2,738 2 5
„ SUBSCRIPTIONS RECEIVED IN ADVANCE		139 5 8
Carried Forward		93,069 6 7

ASSETS. **Cr.**

	£ s. d.	£ s. d.
By INSTITUTION BUILDING AND LEASE :—		
Cost	73,028 6 10	
Less Reserve for Depreciation, being Sinking Fund Premiums paid	1,571 7 6	
		71,456 19 4
„ TOTHILL STREET BUILDINGS AND SITE (at cost)		19,260 17 1
„ SINKING FUND (Premiums paid for Redemption of Cost of Building and Lease)		1,571 7 6
„ LIFE COMPOSITIONS INVESTMENTS (at cost) :—		
£2,600 Natal Zululand Railways 3 % Debentures	2,270 12 0	
£1,500 Lancashire and Yorkshire Railway 4 % Preference Stock	1,513 10 4	
£2,000 Assam Bengal Railways 3 % Stock ...	1,548 0 6	
		5,332 2 10
„ KELVIN LECTURE FUND INVESTMENT (at cost) :—		
£1,000 2½ % Consolidated Stock		862 10 10
„ TRUST FUNDS INVESTMENTS (at cost) :—		
Salomons Scholarship :—		
£1,500 New South Wales 3½ % Stock	1,556 5 9	
£500 Cape of Good Hope 3½ % Stock	570 13 6	
		2,126 19 3
David Hughes Scholarship :—		
£2,045 Staines Reservoirs 3 % Guaranteed Debenture Stock		1,998 15 0
Wilde Benevolent Fund (Capital Account) :—		
£875 Great Eastern Railway Metropolitan 5 % Guaranteed Stock	1,493 16 3	
£215 North Eastern Railway 4 % Guaranteed Stock	250 19 9	
£100 London County 3½ % Stock	101 8 6	
		1,846 4 6
Wilde Benevolent Fund (Income Account) :—		
£250 New South Wales 4 % Stock	251 6 0	
£100 War Loan 3½ % Stock	94 8 8	
		345 14 8
„ LIBRARY * :—		
As per last Balance Sheet	1,439 1 6	
Additions in 1914	108 18 2	
	1,547 19 8	
Less Depreciation (10 %)	154 16 0	
		1,393 3 8
Carried Forward		106,194 14 8

* Exclusive of the Ronalds Library which is held in trust.

BALANCE SHEET—*continued*.

Dr. LIABILITIES—*continued*.

	£ s. d.	£ s. d.
Brought Forward		[illegible] 6 7
To General Fund:—		
Balance at 1st January, 1914	20,171 8 1	
Life Compositions of Deceased Members	95 17 0	
Expended out in 1914 on—		
Books and Binding for Library	108 18 2	
Furniture and Fittings	150 4 0	
Unexpended Revenue for 1914	1,693 10 8	
	22,219 17 11	
Less Depreciation (*per contra*):—		
Library … £133 16 0		
Furniture, Fittings and Apparatus 149 5 1		
	283 1 1	
		21,936 16 10
		[illegible]

ROBERT HAMMOND,
Honorary Treasurer.

P. F. ROWELL,
Secretary.

ASSETS—*continued*. **Cr.**

	£ s. d.	£ s. d.
Brought Forward		[illegible]
By [illegible]:—		
Expenditure on Repairs in 1914	[illegible]	
[illegible]	[illegible]	
[illegible]	[illegible]	
	[illegible]	[illegible]
" Furniture, Fittings and Apparatus:—		
As per last Balance Sheet	[illegible]	
Additions in 1914:—		
Furniture and Fittings	[illegible]	
	[illegible]	
Less Depreciation 5 %	[illegible]	
		[illegible]
" Sundry Debtors		[illegible]
" [illegible]		[illegible]
" General Fund Investments at cost:—		
[illegible]	[illegible]	
[illegible]	[illegible]	
[illegible]		
[illegible]	[illegible]	
[illegible]	[illegible]	
[illegible]	[illegible]	
		[illegible]
" Cash:—		
At Bankers	[illegible]	
Petty Cash	[illegible]	
[illegible]	[illegible]	
		[illegible]
		[illegible]

We beg to report that we have audited the Balance Sheet of the Institution of Electrical Engineers [illegible]

ALLEN, ATTFIELD AND CO.,
Chartered Accountants.

127, Leadenhall Street, E.C.

31st March, 1915.

H. ALABASTER
SYDNEY SHARP } *Honorary Auditors.*

SALOMONS SCHOLARSHIP TRUST FUND (Income).

Dr.	£ s. d.	Cr.	£ s. d.
To Amount paid to Scholars in 1914	75 0 0	By Balance (as per last Account)	23 16 4
,, Balance carried to Balance Sheet	18 16 4	,, Dividends received in 1914	70 0 0
	£93 16 4		£93 16 4

DAVID HUGHES SCHOLARSHIP TRUST FUND (Income).

Dr.	£ s. d.	Cr.	£ s. d.
To Amount paid to Scholars in 1914...	62 10 0	By Balance (as per last Account)	31 15 6
,, Balance carried to Balance Sheet	30 12 6	,, Dividends received in 1914	61 7 0
	£93 2 6		£93 2 6

WILDE BENEVOLENT TRUST FUND (Income).

Dr.	£ s. d.	£ s. d.	Cr.	£ s. d.
To Amount invested during 1914:—			By Balance (as per last Account)	304 6 11
£250 New South Wales 4 % Stock	251 6 0		,, Dividends received in 1914	60 17 0
£100 War Loan $3\frac{1}{2}$ % Stock	94 8 8		,, Interest do. do.	1 16 2
		345 14 8		
,, Balance carried to Balance Sheet		21 5 5		
		£367 0 1		£367 0 1

THE BENEVOLENT FUND OF
THE INSTITUTION OF ELECTRICAL ENGINEERS.

INCOME ACCOUNT FOR THE YEAR 1914

Dr. Expenditure	£ s. d.	Income Cr.	£ s. d.
To Grants	84 2 6	By Balance brought forward from last year	[illegible]
" Postages, Printing, Transfer Expenses, etc.	[illegible] 7	" Dividends on Investments	[illegible]
" Balance carried forward	[illegible] 17 0	" Interest on Deposit	[illegible]
		" Annual Subscriptions	[illegible]
		" Donations of £1 and over	[illegible]
		" Donations under £1	[illegible]
	£[illegible]		£[illegible]

BALANCE SHEET, 31st DECEMBER, 1914

Dr. Liabilities	£ s. d.	Assets Cr.	£ s. d.	£ s. d.
To Capital	[illegible]	By Investments (Capital):—		
" Income	[illegible]	£[illegible] Cape of Good Hope [illegible] Stock		[illegible]
		£[illegible] New South Wales [illegible] Stock		[illegible]
		£[illegible] Great Eastern Railway [illegible] Preference Stock		[illegible]
		£[illegible] North Staffordshire Railway [illegible] Debenture Stock		[illegible]
		£[illegible] East Indian Railway [illegible] Debenture Stock		[illegible]
		£[illegible] London and North Western Railway [illegible] Preference Stock		[illegible]
		£[illegible] New Zealand [illegible] Stock		[illegible]
		£[illegible] Canada [illegible] Stock		[illegible]
				[illegible]
		" Investments (Income):—		
		£[illegible] New South Wales [illegible] Stock	[illegible]	
		£[illegible] War Stock [illegible]	[illegible]	[illegible]
		" Cash Balances:—		
		At Bankers	[illegible]	
		Petty cash	[illegible]	[illegible]
				[illegible]
	£[illegible]			£[illegible]

We have examined the above Accounts with the Receipt Book, Cash Book, Bankers' Pass Book and Vouchers, also the Bankers' Certificate of Investments, and we find them to be correct.

[illegible] ALEXANDER, } Honorary Auditors.
[illegible]

22nd April, 1915.

DISCUSSION ON

"THE POWER SUPPLY OF THE CENTRAL MINING-RAND MINES GROUP."*

MANCHESTER LOCAL SECTION, 13 APRIL, 1915.

Mr. Watson.

Mr. S. J. WATSON: I should like to ask the author whether he can give us any further information to show why the power-plant load factor is something like 75 per cent whereas the load factor of the air system is only, I think, slightly over 30 per cent; and it would help us, perhaps, to deal with that point if he mentions the number of hours worked at the different mines. It is obvious, of course, from the 75 per cent load factor for power that some of the processes are going on throughout the 24 hours, but apparently the processes which employ compressed air are only used for a part of the time. Then there is a rather interesting point in connection with air meters which I should like the author to clear up. He mentions that some arrangement of cams is employed to compensate for varying pressures and varying temperatures. Most air meters, or gas meters, are plain capacity meters and it would be of interest to know how the cams affect this compensation. Figures giving the efficiency of the air-compressor system would also be of interest. I do not know over what distances the air at 100 lb. pressure is transmitted, but it appears from the author's remarks that in the past there have been very serious losses through leakages, etc., and I think it would be useful if he could tell us the overall efficiency. There should be no difficulty in obtaining this figure because the author states that the air is metered at the power station and also on the premises of the consumers.

Mr. McKenzie.

Mr. A. E. MCKENZIE: The author addressed a word of warning, which perhaps some of the engineers present will have to take to heart during the next few years if the ban is not removed from the applications for loans that they may make to the Local Government Board, when he states on page 610 that it is only courting failure to attempt to give a permanent and reliable supply without a proper reserve of generating and transforming plant. Later on the same page he deals with the reserve plant which he considers necessary for a large generating system such as that on the Rand. I think that many central-station engineers in this country would be very pleased indeed to have the reserve of 25 per cent which the author thinks is essential for a large supply undertaking. I cannot understand why it should be necessary for the power company to cover itself in agreements with consumers against frequency variations of 10 per cent, and I do not think there are any supply companies in this country where such variations occur. I should like to have the author's assurance that this guarantee or stipulation is quite unnecessary and that he really did not get variations of more than about 0·5 per cent in each direction, except on rare occasions. With regard to the transformers that are in use on the Rand, I should be very interested to know whether these are of the self-cooled type and whether the author has used any oil-circulating or water-circulating systems for cooling the oil. The expense of three meters for each consumer is, I think, warranted, especially when one considers the immense quantities of power that have to be metered. I consider that each of the three meters forming any series should be of a different type having, preferably, different characteristics. On page 628 the author states that it is a very common and most erroneous practice to install oil switches without considering the fault load that they may be called upon to deal with. In justice to most of the engineers in this country I think that the author may substitute "was" for "is." The fallacy of the above practice has now been very generally recognized in this country for a very long time. Then on page 629 the author asks that switch makers should give a guarantee as to the maximum number of kilowatts at which the switches they install will safely break-circuit at normal voltage. I should like to know what would be the value of such a guarantee.

Mr. Allcock.

Mr. H. ALLCOCK: The point in the paper which caught my attention was the question of pressure variation. I understand the author says that he, or rather his company, as the consumer, was bound to accept electricity varying in pressure by as much as 10 per cent up or down; that being so, the success achieved is very noteworthy, especially having regard to the necessity for speed uniformity in many of their operations. The author's references to the risk of "camming" in the stamp mill, with consequent risk of broken cam shafts and so forth, when the number of falls is raised from 98 to 102 per minute, are both interesting and instructive. Arising out of the question of permissible pressure variation, it seems rather interesting to consider how far power supply to the mines on the Witwatersrand would have been a commercial possibility if the power company had been compelled in the first place to enter into agreements under which they would be called upon to deliver electrical energy within the restricted pressure variations prescribed by our own Board of Trade. It would appear possible, although of course I do not know, that had these restrictions been imposed the power company would not have been established, since we all know that the question of pressure-drop enters very largely into the commercial side of propositions concerning the transmission of large amounts of energy over long distances.

Mr. Lea.

Mr. J. E. LEA: I went out to the Witwatersrand in 1896, and I returned about nine years ago. The changes in mining plant about which the author has told us are really phenomenal in this short space of time. As an example, he mentions that the weight of the battery stamps is now 2,000 lb. The weight of the stamps 10 or 12 years ago varied from 750 to perhaps 1,250 lb. as a maximum. Again, with regard to the amount of ore hauled up in the skips out of the shafts, the heaviest load that I remember hearing of, or seeing, was about 3 or at the most 4 tons. The author in his paper refers to skips holding 8 tons of ore. This is an enormous quan-

* Paper by Mr. J. H. Rider (see p. 609).

[illegible] there are [illegible] now, although for my part I could never quite understand [illegible] Of course, the process is largely a chemical one and much of the work must be kept going. The author has shown to us very clearly what a complete revolution has been [illegible] a thing could take place in England quite so rapidly, but of course they have many things in their favour in South A[illegible] facility for the generation and distribution of electricity wholesale and in a most economical manner.

Cramp. Mr. W. CRAMP: I want to ask the author as one interested in English manufactures, why it is that both in this [illegible] of the mining machinery appears to have been bought anywhere but in this country. If the motors, centrifugal pumps, and compressors are better designed and better made abroad no further reason need be sought. If it is not so, then why is it that in these instances so little of the machinery has been made in this country? Is it simply a matter of price, or are there other influences which rule [illegible] that is referred to in Mr. Hadley's paper is a very interest[illegible] It sometimes happens that a unit simply put forward to get out of an immediate difficulty becomes a regular standard. Such is the history of most English weights, measures, and coins. In this case a unit based upon the C.G.S. system should be put forward by a recognized national authority for general use. On page 611 the author has [illegible] It is rather [illegible] that whereas the electricity meter is, as a rule, much more [illegible] suggested. Three electricity meters are apparently con[illegible] the ordinary polyphase system; it is a [illegible] figures and statements on page 625. I do [illegible] is given as 0·735. Is this simply derived from the fact that W is expressed in lb. weight? Then [illegible] of about three-quarters the diameter of the pipe. We are not told within what limits that may be varied. We are told very reliable results are obtained, but one would like to know within what percentage they are to be relied upon. The present methods of measuring compressed air are very [illegible] than that [illegible] second. Any accurate system of measurement by means of an orifice plate or other instrument which the author can put forward will be useful. But we need to know how the measurement should be made, how the formula is [illegible] connection with this I should like to refer to the pneumometer, which has been adopted a good deal abroad. It depends very much on the same principle as [illegible] mometer and found it to be unreliable and by no means so [illegible]

[illegible]

Mr. Cramp. some makers of compressors will not guarantee their apparatus unless it is driven by belting, and they will take no responsibility whatever for a rope drive. It would be interesting to know whether these rope drives have been entirely successful, whether a heavy flywheel is used in connection with the compressors, whether the tight side of the rope is at the top or at the bottom, and whether any trouble has been experienced from the rope jumping out of the grooves. I should also like to know whether the author has any figures to give us concerning the loss of pressure in the pipes conveying the compressed air. The distances mentioned in the paper seem to be very great. Finally, I notice that the author has used an expression which I do not understand, viz. "root mean square power." The root mean square current and root mean square voltage are adopted because by the use of those two and the power factor the mean power is obtained. But of what use is the root mean square power? Is it of use in specifying the plant? If so, for what purpose?

Mr Rider. Mr. J. H. RIDER (*in reply*) :—

Pressure variations.—Mr. McKenzie asks if the pressure variations were ever more than a very small amount. I have already dealt with this point in my reply to the London discussion (see page 637).

Mr. Allcock appears to be under the impression that the pressure variations affected the speed of the motors. This is, of course, not so, as the speed depends only upon the periodicity of the supply.

Meters.—Mr. Watson asks how the cams in the air meters are arranged to compensate for varying pressures and temperatures. I must refer him to Mr. Hadley's paper,* in which a diagram of the cam arrangements is given.

Mr. Cramp asks if the electric meters are for balanced or unbalanced loads. As all our motors are of the 3-phase type the only amount of unbalanced load is that caused by the lighting arrangements, which are taken as nearly as possible equally from each of the three phases, so that the load may be said to be practically balanced.

Mr. Cramp says it would be interesting to know how the air meters are calibrated. I did not go into the details of this matter in my paper because Mr. Hadley had already dealt with it, and had given a description and illustration of the primary standard air meter belonging to Rand Mines, Limited, at Ferreira Deep. This meter is a displacement meter, which operates at a very low speed, so that the clearances can be made exceedingly fine.

Winders.—Mr. Lea made some interesting remarks regarding the changes which have taken place in mining practice during the last 10 years, and asked whether tapered winding ropes were now used. I do not know of any case of the use of tapered ropes to-day, although their possibilities were discussed at great length in a paper † by Mr. H. C. Behr in 1902. Such a rope, although possessing certain theoretical advantages, did not prove a practical success.

Mr. Cramp asks if cascade motors have been used for winding in South Africa. I do not know of any instance of the use of such motors, and I cannot think that any slight saving of energy by their use would warrant the additional complication.

* *Journal I.E.E.*, vol. 51, p. 2, 1913.

† H. C. BEHR. Winding plants for great depths. *Transactions of the Institution of Mining and Metallurgy*, vol. 11, p. 1, 1901–2

Mr. Rider. *Compressors.*—Mr. Cramp raises a point with reference to the use of ropes for driving compressors, and states that the experience in this country has been that ropes are unsuitable as they would jump out of the grooves. I can only imagine that he is referring to very small compressors, probably of the single-cylinder type without proper flywheels, but I can assure him that in the case of the compressors referred to in the paper rope-driving has been entirely satisfactory. The only flywheel used is one equivalent to that of the original steam-driven compressor, and the tight side of the rope is, of course, arranged to be at the bottom. Mr. Cramp will perhaps remember that one of my slides showed these rope-driven compressors with the ropes running perfectly smoothly, and with good curves.

Mr. Cramp asks how the formula given on page 625 is arrived at. The formula appears to be self-explanatory, excepting that it does not state how the constant 0·735 is derived. It was obtained from the results of tests taken on the standard displacement air meter previously mentioned, and has been proved by both the engineers of Rand Mines, Limited, and of the power company to be accurate. The orifice plate shown in Fig. 9 should have its internal diameter as nearly equal to three-quarters of the internal diameter of the pipe as is practicable, and the object of using the words "about three-quarters" was merely to indicate that mathematical accuracy was not necessary if the area of the orifice is calculated from exact measurements.

Air system.—Both Mr. Watson and Mr. Cramp enquire as to the overall efficiency of the air system and the losses of pressure in the air pipes. I regret that I have no figures available which I could give referring to this matter, as I do not know the pressures at which the power company have to work in their stations to give the contract pressure at the mines.

Transformers.—Mr. McKenzie asks if the transformers are of the self-cooling type. As the transformers belong to the power company I did not deal with their arrangement in my paper, and must refer him to Mr. Hadley's paper for information on this matter.

General.—Mr. Watson asks why the electric load has a load factor of about 75 per cent while the air load has a load factor of only about 34 per cent. The answer is obvious, as, with the exception of the winding plant, the electric load is maintained practically constant day and night, while the air load is very variable and is generally used for drilling only during the morning hours.

In referring to my comments on the sizes of oil switches generally used, I understand Mr. McKenzie to state that in this country it has long been the practice to use oil switches large enough for the energy which they may be called upon to break. I am very glad to note this, but would like to go further and ask switch makers to rate their switches in such a manner. Mr. McKenzie asks what would be the value of such a maker's guarantee. Perhaps the makers will reply.

Mr. Lea asks how much steam plant is now actually left in use. So far as the mines referred to in the paper are concerned, there is no steam plant now in use, but on a number of the other mines on the Rand there is a considerable amount, consisting principally of winders. I can only account for this by the fact that, as the charges to the other

[illegible]

BIRMINGHAM LOCAL SECTION, [illegible] APRIL, [illegible]

Mr. [illegible]: [illegible] came from the United States on account of the exceed- [illegible] electrical machinery of foreign make, but as regards [illegible] rotor had a radial air-gap of only 1 mm., a more usual figure being at least double that amount. The remedy for such troubles lies in the hands of the purchasing engineer; for instance, he can either specify the air-gap or request firms tendering to state the proposed air-gap. With regard [illegible] would appear that the figure obtained by this [illegible] the 6 ft. diameter rotor does not allow much [illegible] safety. A rough approximation, which I have found to agree very closely with the air-gaps of a large number of motors of various makes and sizes, is to take the air-gap as being 1/500th of the rotor diameter. This formula is of course not strictly accurate and gives rather too large a [illegible] the description of the way in which the [illegible] and lines are kept in a high state of efficiency. I [illegible] the author why the drills are not operated electrically [illegible] further information. There would seem to be an opening here for the submersible motor, of which [illegible] are now being made. No mention has been made of the [illegible] case I [illegible] that some transmission lines are made "dead" by the engineers when a storm of exceptional violence occurs.

Mr. [illegible]: I think the paper is a very valuable record of the special conditions and difficulties [illegible] industry, and of the way in which [illegible] that the experience of [illegible] there, although perhaps the manufacturers will have some- [illegible] seems to me that such a method would have great advan- [illegible] under these circumstances I consider [illegible]

Mr. Chattock. of switch for each voltage would be quite justified. I quite agree that oil switches should be rated in terms of breaking capacity in kilowatts as well as in terms of current-carrying capacity. The description given of the difficult conditions under which the air-break contactor switches have to work, and of the excellent way they behave under such conditions when compared with oil-break switches, leads one to hope that the design of the air-break switch will be developed more than it is. The elimination of oil tanks from switchboards would be very advantageous. I am not clear at what voltage these air-break switches have to work. They apparently work both on the stators as well as on the rotors of the machines. As regards the metering of the supplies, the method described of using three meters and taking the mean of the readings is a quite usual arrangement in this country for large supplies; I cannot understand why the energy is metered on the secondary side of the transformers and an allowance made for the transformer losses. It would seem perfectly easy and satisfactory to install the meters on the primary side of the transformers and so arrive at the actual energy supplied.

Dr. Kapp. Dr. G. KAPP: We owe a debt of gratitude to the author for having given so eminently practical a paper, and if other authors would follow his example their papers would benefit us far more than many a highly scientific dissertation bristling with abstruse mathematics. At the same time this feeling of satisfaction at the great usefulness of the paper is overshadowed with a feeling of uneasiness when we read of the failures described in detail on page 630. These are not unavoidable failures, but failures due to dishonest work. That any firm should send out faulty work patched up so as to hide the faults is bad enough, but that the work should be sent knowingly to places where the lives of men depend on honest work is nothing short of scandalous. The author has not disclosed the makers' names and I do not ask him to do so now; but I should be glad if he could in his reply give an assurance that these particular examples of commercial dishonesty did not come from British workshops. When speaking of temperature limits the author states that a rise of only 35 degrees C. is allowed, making, with an air temperature of 35° C., the final temperature only 70° C. This is considerably lower than the Engineering Standards Committee allows even for untreated cotton insulation. There may be a special reason why so low a temperature has been fixed for plant intended for Johannesburg, and it would be interesting to know this reason. In asynchronous motors the air-gap calculated from the author's formula would be smaller than is generally allowed. I suggest that it would be safer to allow a larger air-gap and counteract its detrimental effect on the power factor by using phase advancers. This would also have the incidental advantage of reducing the great variation in voltage mentioned in the paper.

Dr. Garrard. Dr. C. C. GARRARD: I am interested in the author's description of the method of metering adopted, and there is no doubt that for large power consumers the system of having three separate meters in series is a very good one. I should like to ask whether each separate meter of the three was provided with its own current and potential transformers. I presume this would be so. I think the limit of 3 per cent which the author mentions is what can be reasonably expected. The drawings which are given of the electrically-operated contactor switches are interesting. It must not be assumed, however, that such arrangements cannot be obtained in this country. It is unfortunate that the author did not secure quotations; indeed there are several firms in this country who make this type of gear. It appears to me that Fig. 6 has a very serious fault, in that, should the apparatus go wrong in any way, warning is not given and an accident might happen. For example, a break in the battery connection would prevent the warning hooter sounding. It seems to me that any such apparatus should be so constructed that in the event of its going wrong it gives the danger signal and prevents an accident. This is of course a rule which is absolutely followed in all railway signalling. The author takes up the controversial subject of the alleged inability or unwillingness of manufacturers to supply what the customer wants. I trust that the author will not think I am referring to him when I say that in the majority of cases the manufacturer knows very much better what the customer should have than the customer does himself. This is only to be expected, as the manufacturer devotes his life to manufacturing a particular article and knows everything about it; whereas the purchaser probably has a much more superficial acquaintance with the article in question. The fine art of salesmanship, of course, is carefully to conceal this fact and, while letting the customer believe he is getting what he asked for, actually to sell him what he should have. In this way future trouble is avoided, which if it does occur the manufacturer is bound to get blamed for whether it is his fault or not. I think the very fact that these disputes can occur shows the great need which exists for an increased standardization of electrical apparatus. Take the case of electrical oil switches. The state of manufacture of these is at the present time quite chaotic. The author apparently has specified a rating of 800 amperes, 15,000 volts, for his 2,000-volt switches. This is, however, quite an arbitrary figure. As far as I know the only attempt to standardize oil switches has been made by the Verband Deutscher Elektrotechniker in a number of proposals and suggestions issued by them about a year ago. In these suggestions a rule is laid down that the rating of an oil switch must correspond to the maximum current which the switch will have to break on short-circuit in the situation where it is situated. This is undoubtedly right. I am afraid electrical standardization in this country will not make very great progress under present conditions. In this country we have the Engineering Standards Committee, but that Committee has to deal with the whole domain of engineering from locomotives to electrical instruments, consequently electrical standardization can only receive a small proportion of the Committee's attention. It seems to me that the electrical profession and industry must tackle this question in a more serious spirit if this and analogous questions are to arrive at any settlement in the lifetime of any of us.

Mr. F. GREENHALGH: With reference to the operation of oil-immersed stator switches in liquid controllers, I should be interested to learn if the plain butt-contact switches which have been used to such a large extent have satisfactorily withstood arcing, and whether they require much more attention than the open-type carbon-break Mr. Greenhalgh.

[illegible] While the liquid controller [illegible]

[illegible]

Mr. J. M. W[illegible]: [illegible]

[illegible] occur. I consider the sharp-edged orifice a much more reliable means of measuring air flow, but even this must be used with caution. Corrections are necessary for contraction of jet, friction, ratio of orifice to pipe diameter, moisture, etc., and various assumptions such as uniform steady flow and constant density are made, any of which [illegible] on shifting the orifice to a position near the air receiver a very different figure was obtained, the one result being as much too low as the other was too high. As a matter of fact neither of these positions was correct, the correct position being on the outlet side of the air reservoir where [illegible]. The author is quite correct in stating that the volume of [illegible] and experienced makers are careful to allow for this wh[illegible] plate pr[illegible] and a[illegible] simple means of checking the air consumption under working conditions at any point in a large system. The importance of keeping a close check [illegible]

[illegible]

Mr. M. [illegible]: [illegible] Ward Leonard [illegible] motors which have given trouble [illegible] to say is not very high. Have the companies with which the author has been connected similar data and can he give us the benefit of these statistics? I hope it will be found that the number of faulty machines may really be [illegible] course happen with any construction which may be specified. It does not therefore seem to me s[illegible] [illegible]nes of all sizes working under most severe condit[illegible] [illegible]tened up, and in ma[illegible]

[illegible]

Mr. H. Rider

Mr. H. Rider (*in reply*):—

Meters.—Dr. Garrard's queries with regard to the metering of the electrical supplies were answered in my reply to the London discussion, to which I would refer him.

Winders.—Dr. Garrard suggests that the Philip's indicating device has a serious fault, as if there was a break in the circuit the hooter would not sound. This is quite correct, but at the moment I do not see how the apparatus could be arranged to work by opening instead of closing the circuit. It is, however, a point well worth consideration, and shall have my attention. He also states that there are several firms in this country who make contactor switches suitable for 3-phase winder control. I should be very glad indeed to receive from such makers particulars of their switches, as at present I do not know of any.

Mr. Greenhalgh asks whether oil-break switches require more attention than those of the contactor type shown in Fig. 4. That point has already been answered in the paper itself, where the reasons which have induced the mines to give up the use of oil-break switches for winder circuits are fully dealt with. I have had no experience with the type of liquid controller mentioned by Mr. Greenhalgh, but question whether it could be used with advantage on 3-phase winders of large size.

Dr. Kahn asks me to state whether I have a decided preference for Ward Leonard winders. The answer is yes, if the conditions are favourable, but, as is clearly pointed out in the paper, there are many cases in which a 3-phase winder can be used with advantage, and each individual case must be considered on its merits.

In reply to Mr. Chattock, the contactor switches shown in Fig. 4 which are used for the stator circuits of 3-phase winders operate at 2,100 volts.

Distribution.—Mr. Chattock asks if protection of the power circuit on the mines by balanced leakage relays has been considered. Such protection is used by the power company on its own transmission lines, but on the mines simple overload trip gear in the switch houses is only used, and on the motors themselves no-voltage trips are employed. With reference to the use of similar switches for the 2,100-volt and 525-volt circuits in the switch houses, Mr. Chattock considers that a distinct design of switch for each voltage would be justified. It must be remembered, however, that the 525-volt circuits are only for motors under 50 horse-power, while the advantage of only employing one type of switch, with a corresponding reduction in the spare parts, is very great, as the mines are 6,000 miles away from the source of the switch supplies.

Troubles.—Mr. Rosher asks if I will give further particulars of our troubles, but I think those already given are sufficient to point the moral, and no good would result from adding to the list. Either Mr. Rosher's experience must be rather limited, if he has not discovered the flimsiness of design in the great majority of 3-phase motor brush-gears, or our understandings of the meaning of the word do not agree. That he should be sceptical that British-made motors should have stator frames which become distorted under load will not, unfortunately, alter the fact that it was principally in British-made motors that this trouble occurred. Referring to my formula for minimum radial air-gaps, Mr. Rosher considers that with a 6 ft. diameter rotor a minimum radial air-gap of 1·88 mm. (as required by my formula) does not allow a large margin for safety. If the air-gap, as given, is even and regular all round, and is the minimum at any point, it is quite safe. His rule to make the air-gap 1/500th of the rotor diameter would not be practicable.

Mr. Rider

Dr. Kapp expresses the hope that the examples of bad work mentioned in my paper did not come from British workshops. Unfortunately a number of them did. With reference to Dr. Kapp's remarks as to the temperature limits of motors, I would refer him to my reply to the London discussion. With Dr. Kapp's suggestion that it would be safer to allow a larger air-gap than is usual I quite agree, but my experience has been that the air-gaps generally allowed by manufacturers are less than those given by my formula. This may be because many of the air-gaps are not regular.

Dr. Kahn asks what percentage the number of motors which have given trouble bears to the total number. This is a very difficult question to answer, but the principal troubles have occurred in 3-phase winding motors. I cannot agree with Dr. Kahn that the use of dovetailed wedges screwed on to the inner face of the stator frame is good construction under any circumstances. Recent experience in this country with some very large machines has shown how faulty this system can be.

Dr. Garrard's remarks on the subject of manufacturers supplying what the customer wants are worthy of careful reading, as they illustrate the attitude which is so frequently taken up by manufacturers. Dr. Garrard says that "as the manufacturer devotes his life to manufacturing a particular article he knows everything about it." My points are that, while he may know everything about its manufacture, he frequently knows very little indeed about its behaviour in operation, and that he looks at everything purely from the manufacturing point of view. Dr. Garrard certainly throws a great deal of light upon the attitude of manufacturers when he frankly says that "the fine art of salesmanship is while letting the customer believe he is getting what he asked for, actually to sell him what he should have," and this entirely bears out my remarks on the subject. The ordinary commercial salesman is one of the weak spots of the electrical industry, and the sooner manufacturing firms realize this the better it will be for everybody. Dr. Garrard's opinions on this vital point should be compared with those of Dr. Railing (one of his directors) in the London discussion.

Compressors.—Mr. Rosher asks whether it would not have been more advantageous to install electrically-driven compressors on each mine instead of taking the air from the power company. This point was most carefully considered in the early stages of the power contract, and the result of operation has shown that the common air supply is to be preferred.

Mr. Walshe makes some interesting remarks on the subject of air measurements, and I quite agree with him that the orifice plate must be used in the correct position in the pipe line for its indications to be accurate, but this only means that it must be fixed in that part of the pipe line where the air flow is free from pulsations. The figures given in my paper regarding the efficiencies obtained on test by using air meters as against those guaranteed by the maker based on piston displacement are quite correct and refer to an actual case, the figures of which are on record.

[illegible]

DISCUSSION ON

"POWER PLANT TESTING."*

Scottish Local Section, 13 April, [illegible]

[illegible] ing one of the first considerations in buying new plant. At the outset the author gives a few figures to show the importance of low steam consumption and the corresponding saving in fuel, but I think he rather overstates the [illegible] 91 per cent, whereas the average load factor on the plant is agreed to be not over 50 per cent. The effect of this immediately reduces the saving to one half and the figure of £375 should be about £186 per annum. Capitalized on the basis of 8 years' life it will reduce his figure of £3,000 to £1,500. The author states that a generating set taking 1 lb. of steam per kilowatt-hour less than another machine of the same output will be worth £24,000, more than the latter [illegible] tion the extra interest, depreciation, and sinking fund that would have to be provided on the additional £24,000, and this at 8 per cent represents £1,900 per annum, or over [illegible] with the smaller steam consumption mentioned above is only worth £8,600 more than the other on the basis of [illegible] load. I do not wish for a moment to seem to [illegible] ate the importance of steam consumption. As a [illegible] the author could have gone further than he [illegible] steam it follows that 5 per cent less boiler plant will be required. Much interesting information is given in the paper regarding the testing of plant, and any one of the four heads into which the paper is divided might itself form the subject of a paper. Within recent years we have [illegible] of 20 to 24 men; but the importance of having the facts [illegible] every 1/10 lb. of steam above 13·7 lb. meant a penalty of [illegible] any manufacturer would agree to let the plant run for [illegible] ment for the plant on erection; and alternatively, no buyer would agree to pay for the plant until it was officially [illegible] after erection and again 12 months later, but before the [illegible] the efficiency of the turbine at the en[illegible]

[illegible] necessity for testing power plant, not only plant which will be employed on a good load factor but all classes of plant. The buyer feels there is a necessity for an assurance that what he receives is in accordance with the specification and his own ideas. The difficulty arises when the tests [illegible] by both parties. The trouble all along has been that there are so many variables. On getting in tenders the steam [illegible] successful contractor to depart from this stipulation, but [illegible] errors in observation. I notice that the author speaks of [illegible] to have his views as to whether manufacturers are entitled [illegible] surface installed 15 years ago is just as efficient to-day as [illegible]

* [illegible]

Mr. Page. claimed for turbo-alternators. I can confirm what is done in power stations in running new turbines almost continuously. About 15 months ago we installed a 6,000 kw. set in one of our works. It is hardly fair to take the figures for the first 6 months' running, because during that time the turbine has to be "tuned up," but if we take the second 6 months of the first year of that machine's life, I find we ran it for 85 per cent of the possible time, and that it was responsible for 22 million units out of a total output of 33 million units, which only leaves 11 million units to the credit of the other plant in the station. I ought to add that the total capacity of the plant is 22,000 kilowatts. The 6000 kw. set therefore generated two-thirds of the total output, and the other two-thirds of the plant only generated one-third of the total output. From now onwards and until we install still more efficient sets we hope to run this machine on a yearly load factor even better than 85 per cent. This fully bears out the author's contention that a reduction of 1/10 lb. in the steam consumption is extremely valuable. We have tried to get engineers in the boiler houses to digest such information as the author gives in Figs. 1, 2, and 3, and to turn this to beneficial use, but it is extremely difficult to pick up the right class of engineer for boiler-house work. Automatic CO_2 apparatus requires to be used with discretion; the firemen are so apt to cut down air supply and thus lower the output of the boiler in their efforts to get a high percentage of CO_2. Indicating steam meters on each boiler help greatly, not only when worked in conjunction with the CO_2 apparatus, but in the event of a shortage of steam to tell the engineer-in-charge where the trouble lies. On some boilers draught-gauges connected above the fire and between the top of the fire and the back end of the boiler serve not only their legitimate functions but also show at once when the boiler requires cleaning. We have found this to be even a more certain way than relying on the readings of thermometers, as excess air tends to lead one astray when depending upon the thermometers at the boiler and economizer dampers. On the question of fuel analysis, we now buy coal on the daily figures obtained in the electricity department laboratory. The staff soon get expert in the use of the bomb calorimeter, and although for special tests we have analysis made by a consulting chemist the figures thus obtained approximate very closely to our own results. The average calorific value of the coal used each day in our boiler houses is tested on the following day, and the efficiency of the boiler house is afterwards worked out. This involves water meters and coal weighers, but we have now got reliable apparatus of this class and the results obtained enable us to effect economies from time to time. Setting aside a special boiler for testing purposes is in the right direction, but the personal element bulks largely and it is not easy to get the right class of man for this work. A standard requires to be set up as to what is really meant by the efficiency of a boiler. I agree with the author in adhering to the higher calorific value of the coal. Manufacturers who are desirous of quoting their boilers as being very efficient are not much inclined to depart from the method which employs the lower calorific value. I think the one thing that ought to give us no concern in testing is the accuracy of the electrical instruments. Given a good local laboratory and staff the risk of damage to the instruments in transit from the National Physical Laboratory is obviated, and that means a great deal. Some pronouncement is wanted on the exact number of British thermal units in a kilowatt-hour. Marks and Davis put it at 3,415. Some of the engineering year-books give it as high as 3,420, and manufacturers' figures vary from 3,411 to 3,415. We have found that the rotary air pump performs its work very well, but some forms take too long to create the vacuum in the condenser at starting. Where steam or water ejectors are employed this trouble is greatly reduced. I think the figure of 1·3 lb. of air per 1,000 lb. of steam is much too high. An air pump capable of handling that quantity of air and yet only being called upon to deal with about 0·4 lb. per 1,000 is wasting power continually. A better arrangement would be to put in two sets of air pumps each capable of dealing with 0·5 lb. per 1,000, and to run only one under normal conditions, the other being brought into service when there is excessive air leakage or when there is something wrong with the first one. On the question of the size of surface condensers, the allowance of 1 square foot of surface for every 5 lb. of steam seems to me on the large side. Even with a high inlet cooling-water temperature where K has to be increased, 1 square foot to 6 lb. should be enough; and where the inlet cooling-water temperature may be as low as 50° F., $7\frac{1}{2}$ lb. ought to be condensed per square foot. The coefficient of heat transmission referred to as K will repay study. For instance it may be as low as 300 and as high as 1,000 B.Th.U.; it depends upon local conditions. What is the correct value of K for one job is probably quite wrong for the next. The tendency when the cooling surface is not specified is to cheapen the condenser and to work with a high value of K, thus increasing the velocity of the cooling water through the tubes. With plant running on a good load factor this may mean very high pumping costs, and as a rule it generally pays to buy more surface and keep down the friction head against the pumps. The author's statement that a comparatively large condenser will run longer without cleaning appears to be at variance with the generally accepted idea that cooling water passed through a tube at a high velocity will have a scouring effect. If we are to keep up the velocity of the water it means working with a fairly high value of K, and this will not be possible if there is a large margin on the cooling surface. In arranging a test I have always found it pays to explain the whole purpose of the test to everyone taking part in it. It stimulates interest and the assistants get away from the merely mechanical taking of readings.

Mr. Starr. Mr. D. A. STARR: The author's remarks in regard to the importance of a high efficiency of turbo-alternators regardless of prime cost are very well put, especially when illustrated by the example which he gives on page 109. Generally speaking, however, the very thorough tests on different units of plant from boilers and economizers to auxiliaries as set forth in the paper are not only an excellent indication of whether the contractors have fulfilled their guarantees, but in addition good results at the time of the test and taking-over of the plant inspire confidence in the minds of the engineers who are afterwards responsible for the efficient running and commercial results of the whole plant. At the same time in considering the purchase of generating plant I think that high efficiency is not the only feature to consider. Higher efficiency is sometimes obtained at the expense of good

[illegible]

and canteen arrangements.

[illegible] of modern engines, boilers, and power plant is almost entirely due to the work of the electrical profession. I propose to consider more particularly the section of the paper dealing with the testing of boilers. I think the [illegible] for experienced and expert observers. Mere theoretical and book knowledge is not sufficient to ensure accuracy of result, and moreover unless the methods for making the various measurements required in boiler trials are standardized and unless the principles of calculating efficiencies are on the same basis then the results apart from the accuracy of observations are bound to be different and possibly misleading. It has been pointed out by Mr. Wilson on page 136 that the margin for improvement in boiler working is becoming narrower, and I agree with him and Mr. Page that the tendency of some contractors' guarantees is to "creep up to very high figures and is due more to competitive pressure than to scientific development," but I think that the report of the Committee of the Institution of Civil Engineers on tabulating the [illegible] been published, if adhered to by engineers, will tend to attain the object which the author has in view and do away with misleading results of boiler trials which I much deprecate. I think the author along with other experts [illegible] measurements. The CO_2 records whilst having great uses may result, I think, in a waste of money instead of the

[illegible] that the results of a test were [illegible] times even the reverse. On page 112 600° F. is given as [illegible] author's desire for specially designed furnaces for [illegible] class of fuel, but I am afraid that this is ideal. Manufac[illegible] turers have to aim at an average plant, and I should [illegible] become impossible to control the [illegible] points to excessive air leakages in the economizer [illegible] shows the advantages of decreasing such air leakages. With regard to the [illegible] that the test should be started 3 days after cleaning. I [illegible] permissible to blow the soot off the tubes before commenc[illegible] during the test any regulation should be done [illegible] the speed of the grate and not by altering the thickness of [illegible] run before the official trial it would be possible to reg[illegible] alteration either of the speed or [illegible]

[illegible] per [illegible] been placed or proposed under Penalty or [illegible]

Mr. Selvey. hour per kilowatt of maximum continuous capacity. There is no doubt that in a growing station* the load factor of the last new machine will be much higher than that of the station, and I know of machines which week after week are always run at over 90 per cent machine load factor—reckoned on normal full rating (not maximum continuous rating). This results, even in stations where there are a number of machines of similar size, in the most economical machine or machines supplying most of the load. Since members generally insist on taking my approximate statement as intended to be accurate, I should like to take this opportunity of saying that in most cases for machines of 5,000 kilowatts and over I think economy may be considered well worth something like £1 per lb. of steam per kilowatt-hour per kilowatt of maximum continuous capacity (this is about the figure actually quoted by Mr. Lackie for the 6,000 kw. machine). If the load factor does not appear to justify such a high figure when the machine is installed, it will be generally found on examination that the active life of the machine is likely to be long. There are cases where a higher figure is justified.

Mr. Lackie joins with the heads of other large municipal undertakings in finding a considerable field for smaller sizes of plant than those mentioned in the paper. The questions must therefore remain at issue between a knowledge of existing conditions and faith in the immediate future. I shall watch, however, with interest the proposals of municipal engineers for new power stations for the supply of towns of a population of 250,000 and over. Engineers have been very much influenced and handicapped in the past by conditions known to us all, but in laying out new schemes they have a much freer hand. I note that Mr. Lackie is in favour of having the second test 12 months after the initial test, and that he would agree to the contractor examining a machine before the latter is tested the second time. He does not, however, think it feasible to test 6 months after instalment.

As regards the length of reports, I have found it better to condense these documents as much as possible, often to a single sheet. I used to furnish complete records but I found that people used to ring me up on the telephone just to know what was the real significance of the results.

It may be noted from the discussion in various centres that my statement in the seventh paragraph of the paper is strictly correct.

With Mr. Page's remarks I find myself very much in agreement. I think with him that auxiliaries are now sufficiently large to justify an intelligent interest in their efficiency. I am afraid I shall have to leave the question of the margin open. I may say that since the paper was written very notable advances have been made by Mr. Fawssett. One of the most troublesome and obscure errors in 3-phase meters appears to have been largely overcome. I think I am probably correct in stating that such advances would not have come about but for demands made by the Bonus or Penalty Clause inserted in the specification of a machine now nearly ready for testing, the size of which is only equalled by that of one other machine in this country.

The rate of obsolesence of boilers is less than that of turbines since the economy largely resides in the economizer, if the boiler can be run steadily. In some cases, however, the boilers though efficient are obsolete owing to their low pressure and superheat. Mr. Selvey.

Mr. Page's figures are interesting and welcome. Makers of large gas engines are now being called on to guarantee long periods of running, and one maker puts forward figures showing only one stop of 50 hours in a running period of 4,525 hours, *i.e.* 98·8 per cent of the full time. I suppose most makers of turbines would consider their products to be as reliable as gas engines.

As regards CO_2 apparatus, its application certainly must be watched. An occasional sample of ashes analysed for unburnt carbon is a useful check. There is a maximum thickness of fire which can be used for the generation of CO_2 from carbon; any increase of this thickness, without using such a draught as results in lifting fuel off the grate, automatically reduces a portion of the already formed CO_2 to CO. It is practically impossible to supply additional air over the fire in such a way as absolutely to ensure the recombustion of this CO. This is generally understood.

Mr. Page and others have made out a case for local standardizing laboratories, principally owing to the transport trouble. I do not think, however, that any institution can suitably overlap with the National Physical Laboratory, whose experts are very willing to take considerable interest in important cases such as are under discussion. I rather incline to the solution suggested at Birmingham and Manchester that each power undertaking should develop its own sub-standards, as of course has been done in Newcastle to a very considerable degree. The National Physical Laboratory will, however, always be the ultimate standard of reference, especially in cases which will be known as independent tests.

I note with great interest that Glasgow is able to buy coal on analysis. As regards the "lower" calorific value, it may be of interest to state that I recently had to define the expression. After consulting over 20 authorities I came to the conclusion that there is no such thing. There are at least four ways of reckoning the allowance, and a varying selection from these is often arbitrarily made at different places in the same text-book or report.

As regards steam calculations, I always now use the figure given by Marks and Davis. The differences arise from using different "calories." Marks and Davis have adopted the mean B.Th.U., which is 1/180th of the total heat between 32° F. and 212° F. having regard to the varying specific heat of water.

As regards air-pump overload capacity, I take Mr. Page's remarks as tending to support what I have said about the steam-jet system, and I am inclined to indulge in that now famous expression "Wait and See." Mr. Page seems to have appreciated points behind my short note about "K" which have been so far passed over. It has been thought that I put forward $K = 450$ as a high value. It really must be read in correlation with other data. It is quite easy to increase it, and the other data are given as a warning against this. It is growing on me by accumulation of evidence that a high value of K is often associated with bad scaling, especially where sulphates are present in quantity in the water. The high value of K is associated either with a high steam velocity and consequent friction loss on the steam side, or with a high water velocity. It does not appear that the high water velocities sometimes

* See Mr. Page's remarks.

[illegible] formation of scale in tubes in cooling-tower water [illegible]

[illegible] repeatedly hears the opinion expressed that there is [illegible] have no connection whatever with efficiency. Some of [illegible] highly superheated steam in one section and exposed to lower temperatures in another. Others have been due to expansion, vibration, lubrication, insulation, and other matters. Perhaps what is in Mr. Starr's mind is the fact that certain makers of reaction turbines in the past attempted to use very fine clearances over the high-pressure blade-tips. In my connection this has not been left to the makers for some time, the minimum clearance [illegible] ances less than 5 or 6 hundredths of an inch need be aimed at in large modern turbines, the effect on the efficiency [illegible]

[illegible] large water turbines, I [illegible] power took their rise. A saturated solution of salt is prepared in a large tank, and is then pumped at a regular rate into the water-supply pipe. It is assumed that by the time this water has arrived at the tail race the two streams have got uniformly mixed. The ratio of the concentration of [illegible]

[illegible] given by the electrical profession has resulted in the high efficiency of modern engines. This is because power has become a "raw material." I cannot agree, however, with [illegible]

[illegible] trucks or barg[illegible] to hear of the devices which have [illegible] power stations for protection in th[illegible]

[illegible] the removal of all slag from the [illegible] lying on the baffles. As regards [illegible] already mentioned that the internal scale should not [illegible]

[illegible] grates. [illegible] on anyone's part to obscure the results it is very easy for him to do so. In the classes of grates where the thickness depends on the speed, it is necessary to experiment before-[illegible] and final-temperature m[illegible] been specified based on these measurements and the total evaporation.

[illegible] for the [illegible] the questions to the best of my ability.

EXAMINATION PAPERS SET AT THE ASSOCIATE MEMBERSHIP EXAMINATION, APRIL, 1915.

ENGLISH ESSAY.

Examiner: C. C. HAWKINS, M.A., M.I.E.E.

(*Time allowed: 3 hours.*)

INSTRUCTIONS.

Not more than TWO *questions to be answered. One essay of merit will suffice to obtain a pass.*

The maximum number of marks obtainable is the same for each question.

Marks will be awarded for grammar, spelling, punctuation, clear and simple style, orderly presentation of facts or arguments, and power of expressing ideas in good English. Candidates are not necessarily required to have special or technical knowledge of the subject-matter of their essays.

1. Discuss the effect on civilization of any one great invention.

2. Describe what you consider to be the best training for an electrical engineer.

3. What are the chief points on which electrical and magnetic properties and laws find analogies in mechanics and hydraulics, and how far are these analogies true or practically useful?

4. Estimate the influence, good and bad, of newspapers.

5. Write as full an account as you can of the electron theory from a popular (not mathematical) standpoint.

TRANSLATION FROM FRENCH.

Examiner: H. BORNS, PH.D., A.M.I.E.E.

(*Time allowed: 3 hours.*)

(*Particular attention must be paid to clearness of expression and good construction as well as to correct translation.*)

A.

Dès le début de l'application des courants alternatifs au transport de l'énergie à distance, les électriciens s'ingénièrent à remédier aux inconvénients que présente le décalage de phase entre le courant et la tension de la ligne et des alternateurs. Ces inconvénients sont bien connus et il nous suffira de les rappeler brièvement.

La puissance fournie par une génératrice ou transmise par une ligne n'est limitée que par leur échauffement; celui-ci est proportionnel au carré de l'intensité efficace et indépendant de la phase du courant, tandis que la puissance réelle varie seulement comme la composante du courant en phase avec la tension. A ce premier point de vue, on voit immédiatement que les alternateurs et les canalisations seront d'autant mieux utilisés que le facteur de puissance sera plus voisin de l'unité.

En second lieu, pour une même intensité efficace, la chute de tension le long d'une ligne présentant de la self-induction est plus grande lorsque le courant est décalé en arrière de la tension d'utilisation que lorsqu'il est en phase avec elle ou décalé en avance.

Enfin, en ce qui concerne la réaction d'induit, le courant déwatté a une action directement opposée à celle du courant inducteur, tandis que le courant watté produit un flux de réaction transversal, de sorte que, pour maintenir constante la tension aux bornes des alternateurs, il est nécessaire d'augmenter beaucoup plus le courant d'excitation lorsque le facteur de puissance est faible que lorsqu'il diffère peu de l'unité.

La principale cause d'un mauvais facteur de puissance réside dans l'absorption, par les transformateurs et surtout par les moteurs d'induction, de courant en quadrature pour la production de leur champ magnétique. Ce courant réactif augmentant relativement peu avec la charge, il en résulte que le facteur de puissance est plus petit à vide, et à faible charge qu'à pleine charge.

B.

Nous avons exposé dans une note récente, les premiers essais que nous avons entrepris dans une voie nouvelle pour accroître les champs magnétiques donnés par les électro-aimants de nos laboratoires. L'augmentation des champs magnétiques obtenus jusqu'ici est arrêtée par la saturation du fer et l'échauffement des bobines électriques. Nous nous sommes proposé d'accroître surtout le champ dû au seul courant électrique, et nous avons, d'une part, essayé un nouveau mode de refroidissement des bobines, qui permet l'emploi de courants plus intenses; et, d'autre part, nous avons placé les bobines elles-mêmes dans la position qui leur assure l'effet maximum, c'est-à-dire dans l'entrefer et son voisinage immédiat.

La note actuelle donne quelques détails inédits sur ces premiers essais et met en relief une de leurs conséquences. On peut affirmer la possibilité d'avoir des champs magnétiques beaucoup plus grands, égaux ou même supérieurs à 100,000 gauss. Il suffit d'agrandir les nouveaux appareils en conservant leurs dispositions générales et de leur fournir le supplément d'énergie électrique et de liquide réfrigérant exigé par leurs dimensions et par l'accroissement du champ.

Les premiers appareils, par raison d'économie, ont été très petits; mais, ainsi que dans tous les cas semblables, avec des modèles plus grands, la construction et l'excitation électrique sont beaucoup plus faciles. D'après la règle de Kelvin, applicable aux bobines avec ou sans fer, lorsque toutes les dimensions croissent proportionnellement, le champ magnétique reste le même, à condition que

[illegible]

C.

[illegible]

[illegible] tube étroit.

[illegible] si l'électrode qui doit devenir cathode est restée à une [illegible]

D.

[illegible] décharge d'un condensateur dans les conditions où l'on [illegible] utiliser un tube à rayons cathodiques (tube de Braun), soit seul, soit associé au miroir tournant. Tel qu'on l'emploie [illegible]

[illegible] suite du peu d'éclat de la courbe obtenue. J'ai donc cherché à réaliser un tube à rayons cathodiques qui [illegible]

[illegible]

MECHANICS, PHYSICS AND CHEMISTRY

[illegible]

SECTION A. APPLIED MECHANICS.

[illegible]

1. [illegible]

2. [illegible] crane consisting of a [illegible] feet, calculate the loads on the members A B and B C for each ton lifted. What are the reactions at the points of support?

3. [illegible]

(a) [illegible]

(b) the greatest weight which may be placed on the [illegible]

4. [illegible] of negligible weight at its lower end. If a scale-pan weighing 8 lb. is attached to the hook, the spring is [illegible]

oscillate. Describe the nature of the oscillation and state what will govern the number of vibrations per second.

5. Distinguish between Velocity and Acceleration. A mass weighing 100 lb. is placed on the floor of a lift which descends

(*a*) with a constant velocity of 2 feet per second,
(*b*) with a constant acceleration of 2 feet per second per second.

What is the pressure on the floor of the lift in each case?

A train weighing 200 tons is started from rest by a locomotive and finally reaches a steady speed of 30 miles per hour. How is the energy supplied by the locomotive expended both while acceleration is going on, and later when a steady speed is attained? How much energy in foot-tons is theoretically recoverable from the train?

6. Explain the term Centrifugal Force. Give the reason for the super-elevation of the outer rail of a railway and calculate its value in the case of a train running at 30 miles per hour on a curve of 900 ft. radius, the gauge being assumed to be 5 feet in width. How is turning effected in the case of a motor weighing 4,000 lb. describing a circle of 300 ft. radius at a speed of 30 miles per hour on a level meadow? What is the minimum value of the side-frictional grip between the wheels and the ground?

SECTION B. PHYSICS.

Examiner: PROFESSOR H. T. DAVIDGE, B.Sc., M.I.E.E.

(*Not more than* FOUR *questions to be answered.*)

1. State and explain a fundamental law which connects the pressure, volume, and temperature of a given mass of gas. Show, with the aid of a sketch, how you would demonstrate its truth in the case of air.

The air-chamber of a torpedo has a volume of 10 cubic feet. How many pounds of air can it contain at a pressure of 2,000 lb. per square inch and at a temperature of 60° F., if one pound of air occupies 12·38 cubic feet at 32° F. and at atmospheric pressure (14·7 lb. per square inch)?

2. State clearly the phenomena which occur when sounds from distant church bells travel to a listener's ear. What difference in construction and transmission causes the note heard from one bell to differ in pitch from that heard from another?

Describe the details of an experiment

(*a*) to determine the velocity of sound in air,
(*b*) to prove that all sounds travel with the same velocity in air irrespective of pitch and loudness.

3. It is known that an equation of the form $H = \text{constant} \times I^2 R t$ enables one to calculate, in suitable units, the heat developed when a current I passes through a resistance R for a time t seconds. Describe in detail an experiment by which the value of the constant expressed in calories can be found. What would be the relation between the constants if H were also expressed in British Thermal Units instead of calories (1 lb. = 454 grammes)? When H is calculated for a given wire state generally what phenomena have to be taken into account in calculating the temperature reached by the wire?

4. Give a simple sketch of the working part of a moving-coil galvanometer.

A rectangular coil wound with 100 turns of very thin wire, hangs with the longer side vertical in a uniform horizontal magnetic field of strength 4,000 units and with its plane in the direction of the field. The rectangle has a mean height of 8 cm. and a mean width of 2 cm. Rigidly attached to the coil is a horizontal arm 20 cm. long carrying at its end a pencil marking on a paper drum. What is the greatest frictional resistance in dynes between the paper and pencil which can be overcome by a current of one milli-ampere in the coil?

5. What do you understand by the focus of

(*a*) a converging lens,
(*b*) a diverging lens,
(*c*) a concave mirror?

How would you determine experimentally the distance of the focus from the lens in case (*a*)?

Considering a searchlight as an example of case (*c*), show by a sketch how the carbons of an arc lamp are situated relatively to the mirror in order to emit a strictly parallel beam. What is the best form for such a mirror?

6. What is meant by the Coefficient of Linear Expansion of a solid? How could you determine experimentally that of iron?

If a bar of iron 10 ft. long has its temperature lowered 40° C., by how much does it shorten? If such a bar were clamped at its ends between absolutely unyielding supports and its temperature were lowered 40° C., what data would you require in order to calculate the stress produced in the bar (coefficient of linear expansion of iron = 0·000012 per degree Centigrade)?

SECTION C. CHEMISTRY.

Examiner: PROFESSOR H. JACKSON, F.C.S.

(*Not more than* FOUR *questions to be answered.*)

1. Give a short account of the modes of preparation and of the chemical properties of the oxides of sulphur.

2. State what you know of the different forms of phosphorus, and describe any experiments in which you have seen them used.

3. Give a short description of the preparation and chief properties of ozone. What do you understand by the statement that ozone is an endothermic substance?

4. Write a short essay on one of the following

(*a*) the structure and nature of flames,
(*b*) osmotic pressure,
(*c*) diffusion of gases,
(*d*) electrolysis.

5. What are the chief constituents of ordinary coal-gas? Briefly describe the method you would use to identify those which you mention.

6. [illegible]

(a) [illegible]
(b) [illegible]
(c) [illegible]

[illegible]

ELECTRICITY SUPPLY: GENERATION, TRANSMISSION AND DISTRIBUTION. [illegible]

Examiner: P. V. HUNTER, M.I.E.E.

[illegible]

[illegible]

1. What is the yearly [illegible] load factor of a generating [illegible] 43,800,000 units?

2. [illegible] for [illegible] all [illegible] entering the sub-station being bare conductor [illegible]

3. What is the [illegible] operating in parallel?

4. State the number of turbo-alternator sets, and the maximum output of each set, which you would install in a generating station designed for a maximum load of [illegible] the advantages of your proposal.

5. Two three-phase watt-hour meters each fitted with hourly maximum demand indicators are connected in series in a consumer's service cable. If the meters are arranged, one so as to register energy and the other so as [illegible] of the two instruments?

6. Draw a [illegible] starting rotary converter complete with its transformer.

7. The internal losses of a constant-potential transformer operating at normal frequency and voltage are 10 watts at [illegible] calculation of the losses at twice the full load.

8. Why is it desirable to provide a run-away governor on a rotary converter which is converting energy from continuous current to alternating current?

9. Describe and illustrate by a diagram any form of automatic equipment which will disconnect a faulty feeder from a transmission system, the equipment being of such a character that it is not operated by faults external to the feeder.

10. An overhead line has at full load a fall of potential, the resistance and reactance components of which are 3 per cent and 4 per cent [illegible]

[illegible]

11. [illegible]

12. [illegible]

ELECTRICITY SUPPLY: GENERATION, TRANSMISSION AND DISTRIBUTION. [illegible]

[illegible]

[illegible]

[illegible]

1. When a number of synchronous alternating-current [illegible] increasing its excitation on the load of any particular generator?

2. [illegible]

3. What is the distinction between a rotary converter and a motor converter?

4. A 3-wire 3-phase overhead line and a 3-core 3-phase underground cable of equal length and sectional area per [illegible] current of increasing the frequency?

5. An [illegible] rating station [illegible] an increased maximum [illegible]

6. What is [illegible] winding is carrying current?

7. State, in [illegible] governing the [illegible] steam-driven turbo-[illegible]

8. Draw a diagram of the test you would apply in order to locate an earth on one core of a 3-core cable.

9. It is desired to take out of service a high-tension feeder and add a "tee" connection to it. State the sequence of operations to be carried out before the jointer is allowed to commence work on the feeder.

10. A 3-core three-phase feeder five miles long working at a potential of 10,000 volts between conductors at the generator end has a voltage drop due to resistance of 20 volts per mile in each core. What is the efficiency of energy transmission

(*a*) when the load is delivered at unity power factor,
(*b*) when the load is delivered at 0·8 power factor?

11. A transformer has at full load a total resistance voltage drop equal to 1·5 per cent of the secondary terminal pressure at no load, and a total reactance voltage drop equal to 2 per cent of the secondary terminal pressure at no load. What is the minimum voltage that the secondary can deliver at full load expressed as a percentage of no-load voltage, and what is the power factor of the corresponding load?

12. What is the critical speed of a generator, and on what does its numerical value depend?

ELECTRIC LIGHTING AND POWER. (First Paper.)

Examiner: P. V. Hunter, M.I.E.E.

(*Time allowed: 3 hours.*)

(*Not more than* EIGHT *questions to be answered.*)

1. In what respect does the construction of the half-watt lamp differ from the one-watt metal filament lamp? Mention any limitations to the general use of the half-watt lamp.

2. The supply to a large factory is transformed down to 440 volts between phases in a static sub-station. The equipment of the static sub-station includes a 440-volt three-phase switchboard containing a number of feeder panels, each feeder panel controlling the supply to one circuit. The neutral point of the 440-volt supply is earthed. Give a list of the equipment which you consider should be included in each feeder panel.

3. Describe concisely a form of alternating-current exciter which, when connected to the slip-rings of a three-phase induction motor, can be used to adjust the power factor of the current in the stator windings of the motor.

4. Draw diagrams showing the connections of a star-delta three-phase starter for a squirrel-cage induction motor

(*a*) in the starting position,
(*b*) in the running position.

5. What form of tariff would you recommend for the supply of energy for the purpose of charging battery vehicles? State briefly the advantages of the tariff you propose.

6. Two three-phase induction motors are connected to the same circuit, and at the time of maximum load on the circuit, one of the motors has an input of 200 k.v.a., at 0·8 power factor, and the other of 50 k.v.a., at 0·6 power factor. What is the maximum kilovolt-amperes supplied by the circuit, and what is the power factor corresponding thereto?

7. A three-phase induction motor is operating against full-load torque and supplied with normal pressure and frequency. Under these conditions it is capable of exerting a torque equal to $2\frac{1}{2}$ times full-load torque. In the event of the terminal pressure supplied to the motor being reduced, while the frequency remains normal, what is the lowest pressure expressed as a percentage of normal pressure at which the motor will continue to give full-load torque? The torque may be assumed to be proportional to the square of the pressure.

8. Indicate by means of vectors the relation between the terminal potentials of the primary and secondary of a three-phase transformer, the primary being mesh-connected and the secondary being star-connected.

9. Describe any form of frequency indicator, stating the principle on which it operates.

10. Sketch a diagram of the connections of an arrangement of transformers for converting from three-phase to two-phase at the same periodicity.

11. Draw a diagram of connections, and explain the action of an axle-driven train-lighting equipment.

12. The commutator of a high-speed continuous-current motor has been neglected, and is in bad condition. Describe the work which should be done on it to bring it into perfect working order.

ELECTRIC LIGHTING AND POWER.

(Second Paper.)

Examiner: P. V. Hunter, M.I.E.E.

(*Time allowed: 3 hours.*)

(*Not more than* EIGHT *questions to be answered.*)

1. Describe and sketch the construction of a fuse holder for a power circuit, the arrangement of which must comply with the Home Office factory regulations.

2. What are the advantages and disadvantages of the following types of electric heater

(*a*) convectors,
(*b*) lamp radiators,
(*c*) hot wire radiators?

3. Describe and draw a diagram of connections of the equipment you would propose for driving a large planing machine, assuming a continuous-current supply of energy.

4. Describe and illustrate by a sketch a form of rheostat which you would consider suitable for controlling the speed of a three-phase slip-ring induction-type colliery winding motor having an output of 1,000 h.p.

5. [illegible] below the lamps?

6. [illegible]

7. [illegible]

8. [illegible]

9. [illegible]

10. [illegible] it is of vital importance that the supply of lighting should [illegible]

11. Compare the relative merits of the lead cell and iron-nickel Edison cell for driving electric motor vehicles.

12. State how many units of electricity are required to raise the temperature of 600 lb. of water by 100° F. in an electric water heater, assuming that on the average for every 10 units added to the water one unit is lost due to [illegible] Thermal Unit.

ELECTRO-CHEMISTRY AND ELECTRO-METALLURGY. (First Paper.)

Examiner: W. R. C[illegible], M.A., B.Sc., M.I.E.E.

(Time allowed: 3 hours.)

(Not more than [illegible] questions to be answered.)

1. What are the series and parallel systems of copper refining? State the advantages and disadvantages of each.

2. Illustrate the importance of working at a certain current density (within limits) in electro-deposition by any example with which you are familiar, and describe in some detail any one method that has been used to increase the permissible current density materially.

3. [illegible]

4. [illegible]

5. [illegible]

6. [illegible]

7. [illegible]

8. [illegible]

9. Describe the Castner-Kellner vat for the production [illegible] volved.

10. [illegible] cost of production?

11. [illegible] fluid, and the plant that [illegible]

12. [illegible]

ELECTRO-CHEMISTRY AND ELECTRO-METALLURGY. (Second Paper.)

[illegible]

[illegible]

[illegible]

1. Outline the Heroult process of extracting aluminium.

2. [illegible] the electric s[illegible]

3. [illegible] difficulties have been experienced in developing such [illegible]

4. [illegible] and metallurgical) of the induction type of furnace for steel making.

5. What is the "Pinch Effect"? To what is it due, and to what practical use has it been applied?

6. [illegible] electric furnace f[illegible]

7. [illegible] the current density in the electrodes, and the size of the [illegible]

8. Describe the Birkeland-Eyde furnace for the fixation of nitrogen, and outline the process of manufacture of nitrates by this process.

9. Give some account of the difficulties experienced in the fixation of nitrogen by the electric discharge.

10. What methods are employed in testing carbon electrodes for electrolysis?

11. State your views as to whether power should be purchased or generated by the user for electro-chemical purposes. If purchasing energy for electric furnaces, how would you regulate your load to secure the best terms? To what extent do you consider it practicable to use "off-peak" power?

12. Describe some form of apparatus for the purification of water by means of ultra-violet light.

MANUFACTURE OF ELECTRIC MACHINERY.

(First Paper.)

Examiner: Professor M. Walker, M.A., M.I.E.E.

(*Time allowed:* 3 *hours.*)

(*Not more than* EIGHT *questions to be answered.*)

1. How would you determine the total cost per pound of manufacturing iron stampings, say for a 40 h.p. railway motor? Give an example, assuming approximate figures.

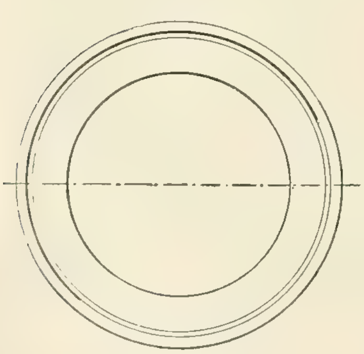


Fig. 1.

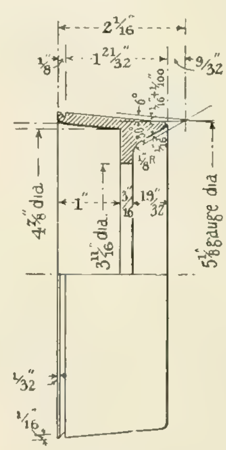


Fig. 2.

2. Figs. 1 and 2 show the elevation and section of the V-ring for a commutator. Of what material would you make this? Describe the process of manufacture and make an estimate of the cost of material and labour, assuming that 500 are required.

3. Describe shortly some method with which you are familiar for conveying manufacturing information from the Drawing Office of an electrical manufacturing works to the foremen in the shops.

4. Make a sketch of a punch and die suitable for punching semi-closed slots in the armature of an induction motor. What circumstances determine the choice between a single slot die, a treble slot die, and a full combination die for striking out a complete stamping at one blow?

5. What are the advantages and disadvantages of manufacturing the pole-pieces of a continuous-current generator

(*a*) from cast steel,
(*b*) from forged steel,
and (*c*) from punched steel?

Consider these methods of manufacture in their bearing on the shape of the poles, the cost of the field-coils, and the performance of the generator.

6. The armature of a tramway motor is returned to the works because it has developed a fault, no particulars of which are given. How would you proceed to find out the nature of the fault?

7. Make a sketch of the supports for the armature winding of a 10,000 kw. turbo-generator to resist the forces which occur on the winding at the moment of short-circuit.

8. What arrangements would you make for the testing of single-phase alternating-current integrating wattmeters in a factory where many hundreds of meters are tested per week?

9. Describe with sketches the best method you know of building the punchings in the frame of a large induction motor where there are as many as 12 segments to the complete circle. How would you ensure accurate registering of the slots?

10. Describe the machining processes on the cast-steel framework of a railway motor, and show how the accuracy of machining is ensured from step to step.

11. What arrangements would you make in an electrical factory for testing insulating materials as they are delivered from the maker?

12. What are the relative advantages of continuous-current motors and three-phase induction motors as applied to the driving of machinery in an electrical factory?

MANUFACTURE OF ELECTRIC MACHINERY.

(Second Paper.)

Examiner: Professor M. Walker, M.A., M.I.E.E.

(*Time allowed:* 3 *hours.*)

(*Not more than* EIGHT *questions to be answered.*)

1. In a dynamo factory it is necessary to have made a great number of parts for one machine. What records would you keep and what method would you employ, in order to ensure that all the parts of a machine are finished at the right time?

2. [illegible]

3. [illegible]

4. [illegible]

5. [illegible]

6. How would you proceed to fix the piecework rates [illegible]

[illegible]

7. [illegible] to the time of shipping.

8. [illegible] material required to manufacture 5,000 holders.

9. How does the frequency of a polyphase circuit affect

(*a*) the design,
(*b*) the performance

[illegible]

FIG. 3.

10. [illegible]

FIG. 4.

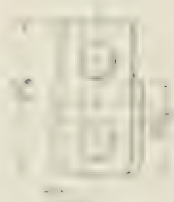


FIG. 5.

11. [illegible] manufacture of circuit-breakers for high-voltage feeders in large generating stations.

12. [illegible] varnished linen affected

(*a*) [illegible]
(*b*) by rise of temperature,
[illegible]

PROCEEDINGS OF THE INSTITUTION.

ORDINARY MEETING OF 29 APRIL, 1915.

Proceedings of the 580th Ordinary Meeting of The Institution of Electrical Engineers, held on Thursday, 29 April, 1915—Sir JOHN SNELL, President, in the chair.

The minutes of the Ordinary Meeting held on 15 April, 1915, were taken as read, and confirmed.

The list of candidates for election and transfer approved by the Council for ballot was taken as read, and was ordered to be suspended in the Hall.

The following donations were announced as having been received, and the thanks of the meeting were accorded to the donors :—

Benevolent Fund : R. B. Burrowes, F. R. Davenport, Messrs. Evershed & Vignoles, Sir John Gavey, C.B., W. J. Head, The Incorporated Municipal Electrical Association, J. W. Kempster, J. E. Kingsbury, S. W. Melsom, The Osram Lamp Works, Ltd., S. L. Pearce, H. A. Ratcliff, J. H. Rider, D. E. Roberts, J. F. Shipley, C. Stewart, B.Sc., and A. A. C. Swinton.

Library: The Cambridge University Press, and L. Gaster.

Mr. F. B. O. Hawes, Professor J. T. Morris, and Mr. E. A. Nash were appointed scrutineers of the ballot for the election of new Members of Council.

A paper by Mr. Alfred Dickinson, Member, entitled "The Bombay Hydro-electric Scheme" (see page 693), was read and discussed, and the meeting adjourned at 9.58 p.m.

ELECTION OF NEW MEMBERS OF COUNCIL.

The Scrutineers (Mr. F. B. O. Hawes, Professor J. T. Morris, and Mr. E. A. Nash) appointed at the meeting of the 29th April, 1915, have reported to the President that they have examined the Ballot Papers and that the following have been found to be duly elected :—

President: C. P. Sparks.
Vice-Presidents : Dr. A. Russell and R. T. Smith.
Honorary Treasurer : R. Hammond.
Ordinary Members of Council: W. A. Chamen, H. Dickinson, J. Hunter Gray, Professor T. Mather, F.R.S., H. F. Proctor, and G. S. Ram.

The Council for the year 1915–1916 will therefore be constituted as follows :—

COUNCIL 1915–1916.

President.
C. P. SPARKS.

The Past Presidents.

Vice-Presidents.
J. S. HIGHFIELD.
DR. A. RUSSELL.
R. T. SMITH.
C. H. WORDINGHAM.

Honorary Treasurer.
R. HAMMOND.

Ordinary Members of Council.
F. E. BERRY.
W. A. CHAMEN.
R. A. CHATTOCK.
J. CHRISTIE.
E. RUSSELL CLARKE.
H. DICKINSON.
J. HUNTER GRAY.
MAJOR E. O. HENRICI, R.E.
PROFESSOR B. HOPKINSON, F.R.S.
A. W. MARTIN.

Ordinary Members of Council *(continued).*
PROFESSOR T. MATHER, F.R.S.
A. M. OGILVIE, C.B.
G. W. PARTRIDGE.
W. H. PATCHELL.
H. F. PROCTOR.
G. S. RAM.
R. J. WALLIS-JONES.
W. B. WOODHOUSE.

The Chairman and Immediate Past-Chairman of each Local Section.

THE JOURNAL OF
The Institution of Electrical Engineers

Vol. 53. 1 JUNE, 1915. No. 249.

ADDRESS TO THE STUDENTS' SECTION.

By Sir John Snell, President.

[illegible]

[illegible] the great importance of attention to detail; thirdly, the [illegible] of electrical engineering in the future.

[illegible]

[illegible] which will bring its own reward, or to hard study, to [illegible] of life, or to whatever it may be applied. [illegible]

[illegible] life before you with all it[illegible] go to the formation of character. The [illegible] be required eventually to fill—have the unce[illegible] engineers, who at the end of their college and workshop [illegible] for myself, I hav[illegible]

[illegible] detail. That is a sort of natural development of the few [illegible]

ledge, and which also came to mine, of a stud in an important part of a generator which appeared to have been properly finished and showed a thread through the nut. But when, some time after the machine had been erected and running, that nut was taken off, it was found that the real stud entered the nut by only about two threads, and that a dummy stud had been put into the remainder of the nut so as to look as if the whole stud had been properly finished. Such a piece of work as that is criminal. That is what I mean by saying that if you are supervising work you must see that that work is not done in that scanty, improper, and wrong way. You know what Longfellow says :—

> "In the elder days of art
> Builders wrought with greatest care
> Both the unseen and the seen
> For the gods saw everywhere."

That I believe is a precept which ought to be applied to all the work that one undertakes in life. Do every job as if you had to live with it afterwards. One of the chief complaints I have heard made against my own class, the consulting engineer, is: Yes, the consulting engineer designs his scheme and supervises the erection of it, and when the contractor has finished the work and the period of maintenance has expired, he receives his final fee and departs happily, and then the unfortunate resident engineer comes in and begins to find out all the faults both in the design and in the carrying out of the scheme. No man of course is free from committing mistakes. We have all made mistakes and we shall continue to make mistakes—*humanum est errare*—but it is one's duty to make as few mistakes as possible. I should like to see entirely removed that reproof which I have heard so many times uttered against consulting engineers, and it can only be removed by attention to detail and by doing the work as if one were going to live with it after its construction.

I think one of the chief dangers which attach to engineers is a too great gift of what I may term intuition. It has been a great fault of my own all through life. For some reason or other, if one is asked to write a report upon some particular work one sees very quickly the true answer to the question. That is a great danger, because if one can intuitively arrive at what one believes to be the proper solution of the problem one is apt not to be able to prove it so conclusively to the people for whom the report is destined. It is, I can assure you from bitter and long experience, a very great trial when one knows intuitively what one's report is going to prove, to have to sit down and laboriously prove that the answer is right. So I say: Beware of the danger of being too intuitive.

There is often a want of a proper knowledge of true economy. I believe that some of the reasons why young engineers are dissatisfied at times with the progress they make is that they have been perhaps too much college-bred, and have not been well enough trained in what I may term true economic engineering. So I say to all students who desire to get on—and of course every one of you desires that—Do not neglect the economic side of engineering. It is said that any engineer if plenty of money is placed at his disposal can carry out any work that is possible of achievement, but the successful engineer is the man who does the work thoroughly and properly at a minimum expenditure of money. I did not mean, when I said just now that there was a want of a proper knowledge of true economy, that people were unable to live within the limits of their incomes—though there are many of those unfortunate people to be found—but rather there is an inexperience in the conservation of things valuable and an inappreciation sometimes of the real value of engineering materials and costs. The waste which has taken place during the last century has been appalling. I do not refer to the waste of life so much as to engineering waste. Doubtless it will be said that it is a corollary of the gradual improvement and evolution of engineering appliances. That is so, to some extent; nevertheless the prodigality of engineers and manufacturers in the application of coal, to take one example—even when their knowledge enabled them to do better—has been thriftless to a degree. Take the case of many of our factories. I know of an instance (I am afraid it is rather an old story) of a large mill with a thoroughly good main engine, but with an array of smaller outlying machines, steam-driven, and simply wasting steam not by the pound (lb.) but by the thousands of pounds per hour. There were numerous boilers at 60 lb. per sq. in. pressure when a third of the number at a higher pressure and with other improvements would have sufficed. There was a loss of coal each year representing several thousands of pounds sterling. Or take the waste of energy from the exhaust steam of rolling-mill engines, or from blast-furnace blowing-engines, which has gone on for several decades. Now happily these facts are realized, such waste is being averted and the energy is being utilized and turned to good account for commercial purposes. These are some of many instances. In our own particular line there is the appreciation of the proper system of distribution to be adopted in some specific case—the appreciation of the relative values of copper and aluminium—the value of the condensation of steam, and when and when not to adopt it—the economic position of the site for a power house—the value of materials in the design of generators, and many like subjects. The wit of man is continually striving to get more out of Nature's materials and to design more economic appliances, and it is you who will be called upon to do your share of this work. Electrical machines have been brought to a high pitch of efficiency, but there is still an appalling inefficiency in the effective use of the thermal capabilities of coal. Steam-driven electrical plant under the best conditions only transforms some 12 to 15 per cent of the available energy, and gas-driven electrical plant under favourable conditions some 25 to 30 per cent; there is much leeway therefore to make up. Our industry has been the agency whereby the use of large water-power has been made possible. Still, the cost of impounding and the other necessary works sometimes make water-power less economical than coal or oil-fired plant. These are some of the problems where a real understanding of economical application comes in.

It is, of course, often wise policy to spend more capital to obtain cheaper production of energy. This is one of the functions of the engineer, viz. to get the most he can out of the money spent. Therefore I urge you in whatever work you undertake to consider always: What will this cost? Will the results be worth the money? That is the true test of most engineering improvements and designs. I have seen a public electricity-supply station most ornately finished in elaborate tiles from floor to roof and having a

[illegible] done.

[illegible] But even if they have taken the college [illegible] side and have applied themselves specifically [illegible] civil engineers and mechanical engineers having no real [illegible]

[illegible] neers will not have quite the monopoly that they have [illegible] had the opportunity and the inclination to [illegible]

What does this mean? It points out that the future education and training of electrical engineers must not be [illegible]

[illegible] do; the young engineer's whole future career in my [illegible] is that young men are turned out into salaried positions [illegible] broader and better foundation [illegible] structure of their life's work. [illegible]

You must also acquire a working knowledge of workshop tools and tackle so that you may be ready to deal with emergencies with intelligence and therefore with confidence.

I have not got to the end of the requirements yet. We Britons are notoriously bad linguists. I strongly recommend you to learn French, and, if possible, Spanish, a cognate language, and those of you who can are advised by a great many people to learn a little Russian (I rather pity the man who has to do it) and thus be able to hold your own if and when you do go pioneering in new countries. It is a great handicap and also a humiliation to have to depend on the perhaps imperfect translation of a third person. In addition to all those labours, and as a further widening of one's education, I suggest that you should read history, even if only as a relaxation from your other labours. It teaches one the mistakes as well as the successes of our ancestors, and therefore it teaches one what to avoid and how to benefit by previous experience. If you can also work up a keenness for geology or astronomy, or even botany, it will help you to get that *scientia scientiarum*, as Charles Kingsley called it, the habit of observation. Upon that last point I have the strongest views. I know that in my own young career the fact that I had a great keenness for geology and for botany and for what generally used to be known as natural history, was a very great help in teaching one to see and to observe, *i.e.* to get what one used to be told was a "quick eye." It does teach one, because even in structural botany one learns much that can be applied to one's own engineering work.

Now, lastly—and on this you naturally must feel very strongly—what are the prospects of electrical engineering in the future? I may have rather discouraged you just now by saying that in my belief all engineers would have to possess some knowledge of electricity, and that except in the case of the comparatively few specialists all electrical engineers would also have to be engineers of some other kind, that is civil engineers or mechanical engineers. Some of you may think that, especially for the President to say such a thing, it is a little discouraging to you. But I must not be misunderstood. I do not mean to say that because you do not happen to have a knowledge of sea defence-walls, the building of moles or of dams, the impounding of water, irrigation works, or whatever some of the bigger civil engineering works may consist of, that therefore you are not going to succeed in life. I do not mean that at all. What I do believe is that you should broaden your education by not confining yourself to electrical engineering subjects purely. I know there is very much to learn even in that, and that time is short, but be content not to develop too high a mathematical knowledge or too abstruse a knowledge even of the applications of electricity if by so doing you neglect a proper appreciation of what I may term the old type of civil-engineering work. I am going to say something to you presently about some of you having to go abroad, because I am confident from what I have been told by my old friends and assistants and others who have been abroad that they have to put their hands to many things, in addition to designing and constructing electrical work purely. They have to do other work, perhaps even to design a small dam (if it is a big one with important stresses on it they will of course get some specialist to help them in work of that sort), or do levelling, or give a pronouncement upon the foundations upon which they propose to erect heavy weights. All matters of that kind which are a sort of common civil-engineering work are certainly not outside the ambit of an electrical engineer's training. That is what I mean. I do not mean to say that the electrical engineer *qua* electrical engineer is going to disappear from the face of the earth. I do not believe that for a moment. Electrical engineers, owing to the minuteness and the accuracy of their training, have taught other engineers how to measure accurately more than perhaps any other class of engineer. I think that electrical engineers, with the breadth of education to which I have just referred, will probably oust a great many engineers in the next generation from their work, rather than that electrical engineers will be wholly and utterly merged in the mechanical and civil engineering branches. I am not a very old man, but I began very early in life and things have changed a good deal since my younger days. When I was 20 years of age I was earning quite a comfortable income. Nowadays, owing to the greater knowledge that has to be acquired, men cannot begin their professional life at the earliest until they are above 20 years of age. I said just now that I think it is a great mistake that young men 20, 21, or 22 years old should be expected to keep themselves. I think that is too rapid a result from their education. I think, in other than exceptional cases, if they remain as students for a year or two longer they will reap a fuller benefit later on in life.

Many hundreds of young men are leaving the universities and technical colleges every year as "electrical engineers," and in this country there are not sufficient places for them to fill; the supply is greater than the demand. You must forgive me if I tell you what in my belief are home truths, but I should be failing in my duty if I did not speak quite boldly upon this subject. Therefore we now find that very many are quite unable to get work in their profession, and others find that when vacancies occur there is a downward trend in the salaries attached to the posts. Except in the comparatively few big posts there is no doubt that generally the salaries of electrical engineers are now smaller than they were five years ago, at any rate in the public positions, though the actual cost of living has gone up in that interval, and will go up a great deal more in the future. What is the deduction to be drawn from these facts? It is surely this: that our young engineers must be prepared to go abroad. They have, it may be said, a national mission to perform. The engineer is prima facie the pioneer of civilization and is one of the principal agents in improving man's environment. British engineers by their influence abroad can improve and broaden the industrial output of this country, and can also act as missionaries of British influence. I am not speaking politically, though that may also be affected by the wise conduct of their own affairs. When asked by young men about their futures I have often regretted to find that they were not disposed to go abroad. I suppose in the course of a year I must see many scores of young men who want to improve their positions, or who are out of jobs and want me to help them. They come with letters of recommendation and many of them have an excellent training

[illegible] which is a [illegible]

[illegible] I think that, as a general statement, this is a mistaken [illegible] not always be applicable at home, but I have generally found it is those who have not been conspicuously successful abroad who come home bringing this complaint. At home or abroad, I advise you to broaden your experience. Do not stay "on the switchboard" for several years if you can avoid it, and do not keep your eyes fixed only on the meters and the log books; get all the experience you can of stoking, engine-driving, repairs, and, if you possibly can, of distribution work. Join a field class in your spare time and do some [illegible] deep groove and narrow their experience so that they destroy their initiative and render themselves unfit for other classes of work. Therefore I ask you, as a duty to your race and to yourselves, not to shrink when the time [illegible] night, to leave home and strike out in pastures new, carrying with you a full sense of the responsibility which will rest on you to do whatever work may be given with [illegible] abroad, consider the possibilities of the offer, of course like prudent persons, but let no weakening and undermining idea of little hardships or family severance, etc., distort your judgment. Our birthright consists in the advantages we possess as a race which have been derived [illegible] tion do our share in the development of our knowledge of [illegible]

[illegible] fitted him for anything better. He is "spent." But the [illegible] ambitions, but put a curb on them, [illegible] turning out your work, knowing that [illegible] worker always has his reward

[illegible] "The best reward for having wro[illegible] have more to do; and he that has been faithful [illegible] [illegible] of my [illegible], I say emphatically that there is no such thing as [illegible] there is much truth in the old adage that "genius is the art of taking pains," and that all good work honestly done [illegible] be honest to yourself and to your employers; do whatever is given you with [illegible] can safely leave the [illegible] have asked an assistant to do something which I knew to be well within his capabilities, to be repeatedly appealed to by him on this detail or on that because he is afraid of [illegible] and go at y[illegible]

tions, which are Truth. The latest Gospel in this world is: Know thy work and do it." Let each job done be a "stepping-stone to higher things."

Young men—I know from my own feelings when a younger man—are impatient too, if what they feel is good work is not immediately awarded a "prize." That is unwise, because I have said I am certain the reward will come unerringly, even if we cannot at once point to it. The reward may be latent, and with the addition of yet a little more good work may suddenly, and often quite unexpectedly, burst into steam. Recollect, however,

> "The noblest service comes from nameless hands,
> And the best servant does his work unseen."

One last word—and it is of great importance to engineers —know your workmen, understand their characters. You will have to superintend many men in later life. The workman, of whatever rank, is a real good fellow when you know him and get below his shyness and fear of being patronized and "put upon." In that delightful book of G. H. Lorimer's, the self-made merchant tells his son: "Keep close to your men. When a fellow's sitting on top of a mountain he's in a mighty dignified and exalted position, but if he's gazing at the clouds he's missing a heap of interesting and important doings down in the valley. Never lose your dignity, of course, but tie it up in all the red tape you can find around in the office and tuck it away in the safe. A competent boss can move among his men without having to draw an imaginary line between them, because they will see the real one if it exists." "Authority swells up some fellows so that they can't see their corns, but a wise man tries to cure his own while remembering not to tread on his neighbour's." There is a good deal of good sound common sense in that. My remarks may have given you the impression of a sermon; but I have felt the responsibility of addressing you, and I have wished to help by drawing from my own experience in life, and I earnestly hope I may have given you some help.

It is a very great pleasure indeed to me to have come here to-night and met you. It is difficult perhaps in a short address like this for you thoroughly to appreciate all that I have said, but I think I can sum it up thus: That you should work hard and seriously. Be wise enough to take advantage of every opportunity that comes your way. Try not to be too impatient about achieving success immediately, because speaking from my own experience in life you will find that success will come, as I have said, unerringly. It will come sooner or later, but it will come to those who deserve it.

DEVELOPMENT OF MAIN-LINE SIGNALLING ON RAILWAYS

By W. C. Acfield

[illegible]

[illegible]

[illegible] following trains; and in the case of junctions, between converging or crossing trains. The signalling of trains on [illegible] wherever such signals are requisite to protect obstruct[illegible]

The signal-boxes at which block telegraph working is [illegible] line of rails, and the system under which these instruments are to be worked and the mode of indicating the description of approaching trains are laid down in a code of [illegible] for obstructions on the line and irregularities of working, there are a large number of different bell codes numbering [illegible]ed", and all signals must [illegible] from the signal-box ahead, which is indicated on the block instrument in the signal-box. The type of block instrument generally in use is of the 3-position type, the [illegible]

[illegible] meant absolute safety. It is only too ev[illegible]

Lock and Block

[illegible] of points and signal appliances were distinct, and were worked independently of one another, but it soon became [illegible] an electric treadle, operated by the passing of a train over the railway, unlocked the block instrument in the train-on-line position.

"Lock and block" is a very well-known [illegible] Ferreira; but it may be said that the most generally adopted system is that of Sykes.

"Lock and block" plays an important part in the work[illegible] mineral working it is not necessary to have so large a [illegible] boxes at [illegible]

home signal of the block signal-box in advance, or is waiting at the starting or advance-starting signal of the said advance section.

To enable closer working to be carried out a mechanical arrangement is provided, viz. the Cancel Key, in the use of which there is unfortunately no check upon the signalman. By injudicious use of this key several serious collisions have occurred, the signalman, although finding his instruments locked up actually by the proper means of working, having overlooked the existence of a train in the section and freed the appliance by releasing it with the cancel key; one of the most recent cases being the serious collision at Waterloo Junction on the South Eastern & Chatham Railway.

It can thus be seen that the weak spot in a lock and block system is the means provided for enabling the signalman to release the electrical locking between the block instruments and the levers working the signals, either in the event of a train being accepted and such train for some reason or other not going forward on its journey; the failure of the treadle to do its proper work; or the shunting backwards of trains over treadles during the operation of dividing or making up trains.

Special arrangements have in a comparatively few cases been installed to provide for permissive working under Rule No. 5, "Section clear but station blocked", in combination with the ordinary lock and block working; a second signal, known as a calling-on arm, being fixed under the home signal in the rear, and the instruments duplicated in the signal-box for special working, which enables a second train to enter the section already occupied by a train at the station in advance.

A switching handle is provided in the signal-box for changing from ordinary to special working, and when used becomes locked by "plunging" for a second train until the previous train has cleared out of the section and the treadle has been actuated. With this method the cancel key has still to be retained to deal with failures of apparatus, and there is still the loophole for using the key irregularly. Treadles are of two kinds:—

(*a*) Treadles operated by the first wheel of the train.
(*b*) Treadles operated by the last vehicle of the train.

The latter type ensures the whole of the train having passed over the treadle before the release in the block instrument is given; and in short sections where trains are liable to come to rest with the rear vehicles overhanging the treadle this is a very desirable form to use.

The treadles in use to-day are of the mercury type, which are far preferable to the old form of rubbing contact previously introduced. The mercury is contained in a box or chamber, and is set in motion by the deflection of the rail to which the treadle is attached; the mercury is caused to flow over the contact points either by the movement of pivoted levers or is pumped up by a piston depressed by the rail upon which trains run.

Interlocking Block.

This is a form of lock and block in use to a large extent on the Midland Railway (which railway it is the author's privilege to serve), and furnishes the necessary elasticity for passenger and goods traffic working under Rules Nos. 3 and 5 before mentioned. The instrument used (Figs. 1 and 2) is known as the Rotary Block, and is of the pegging handle and vertical-needle type. The handle stands normally vertical in the "blocked position", and to give the "line clear" and "train on line" indications is moved in a clockwise direction. There is a ratchet movement in the instrument to prevent the handle being turned in a reverse direction, and this prevents a signal being given a second time unless the handle has been rotated to both the "line clear" and "train on line" positions.

"Line clear" being given removes the electric lock on the starting signal in the rear section, and "train on line" being given drops the said lock ready to fall into position again when the starting-signal lever in the rear is placed to danger. After "line clear" has been given by the first movement the handle is then turned to the "train on line" position and becomes locked in that position so that it cannot be moved either forward or backward until a

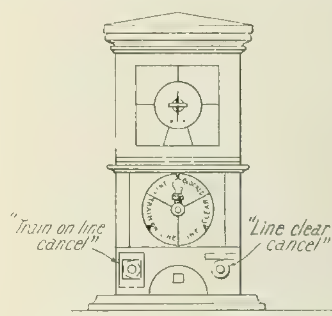


Fig. 1.—Rotary Interlocking Block (Pegging Instrument).

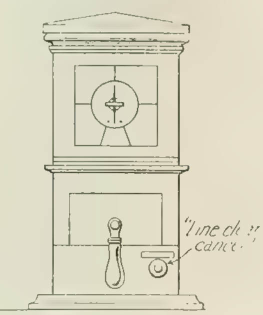


Fig. 2.—Rotary Interlocking Block (Non-pegging Instrument).

releasing treadle, fixed on the railway inside the home signal, has been operated by the accepted train, after which the handle is free to be turned to its normal and vertical position.

To prevent the possibility of "line clear" being given for a train to approach from the rear section whilst the home signal is at "clear", a lock is provided in the block instrument, and a switch on the home-signal lever, which ensures the home signal being at danger before the handle of the instrument can be turned from the blocked or normal position. With this in combination with rotation mechanical locking on the home and starting, or shunting signals, the signalman is compelled to go through the operations necessary for passing a train through the section, thereby making certain that the starting signal if once lowered must be returned to the danger position before the home signal can be used a second time.

The rotation locking referred to provides that the home signal pulled over and replaced becomes locked until the starting or shunting signals, where the latter exist, have been pulled over and replaced; and upon the completion of this operation the starting signal is once more automatically electrically locked by the advance section, and is only released by "line clear" being given from the advance section as before described.

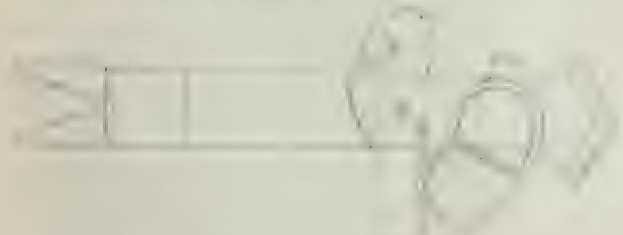
[illegible]

[illegible] "on line" cancel on the left-hand side, this arrangement [illegible] block.

[illegible] general practice.

[illegible]

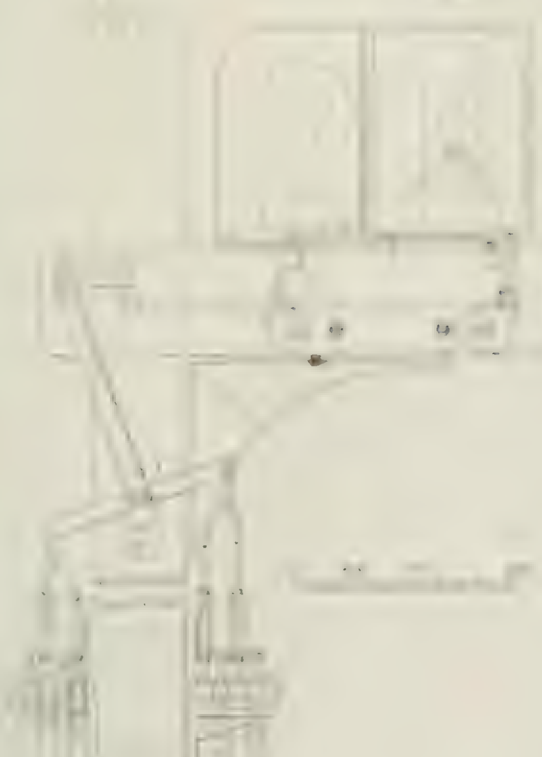
[illegible] indicate that the driver should stop to take up passengers, [illegible]



[illegible]

[illegible] only "danger" and "clear". History is, however, now [illegible]

[illegible]



[illegible]

a considerable extent in America for automatic block signalling: Horizontal for "stop", inclined 45° for "caution", and vertical for "proceed". Such signals are electrically operated and controlled by means of track-circuited lines, as hereafter referred to, and were introduced in the year 1900.

The subject of the Distant Signal is one that not only has been much discussed in the past, but is constantly being brought up to-day. There is little doubt that in past years the introduction of distant signals for each route defined by home signals has been overdone, with the consequent result that most railways are now devoting their attention to the abolition of such signals where practicable, and recommendations have been made by the Board of Trade, in official enquiries into accidents, to dispense with the use of "inner distant" signals. The author suggests, however, that no hard-and-fast rule can be laid down on this point, as it is purely a question of dealing with each problem on its merits, bearing in mind the speeds, gradients, and speeding-up of traffic generally, and that the wholesale abolition of such signals cannot be justified. For instance, where a goods line runs parallel with a passenger line, and there is a junction between them, the absence of a second distant signal for the junction, particularly on a rising gradient, would result in an unnecessary reduction in the speed of the goods train as it approached the said junction.

Signal arms of various lengths and forms, made in wood and enamelled iron, are used for main lines, goods, shunting, and calling-on purposes, and are provided with red, green, and purple glasses in the spectacles, according to the custom of the various railways. It is to be hoped, however, that before long the type of signal arms will be standardized, as it seems a fallacy for drivers of one company running over another company's system to require special experience in order to read the different forms of signals which really perform the same function. It must be admitted that American railways are somewhat in advance of English railways in this respect.

Distant distinguishing lamps.—Although distant arms are distinguishable in daylight by the notched arm, there has been no general move towards giving a similar indication at night-time. Several attempts have, however, been made to introduce a means of giving a distinction; one of the most effective being a notch form in a white light on the right-hand side of the signal lamp (Fig. 3), and this has been adopted by several of the more important railways. This white indication is quite distinguishable at a distance of 250 yards from the signal, and in many cases is a useful adjunct in traffic working. There is no doubt that such an indication at the outermost distant signal leading to shorter sections, where the distant arms are placed under home or starting signals, would be a great advantage.

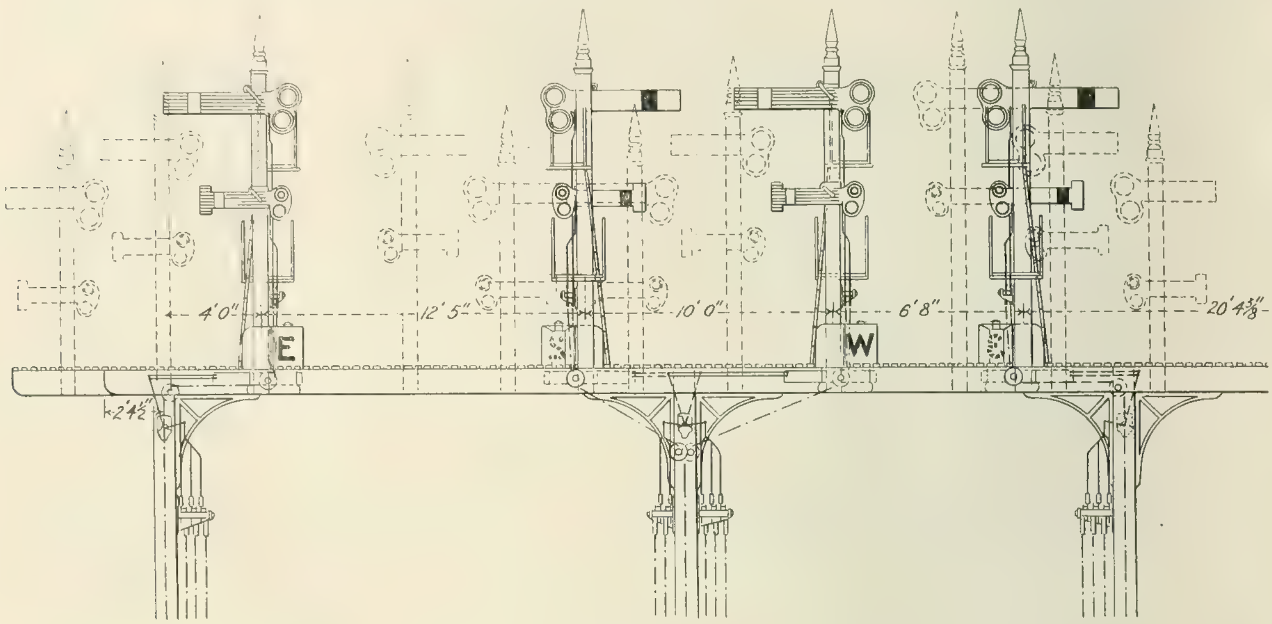
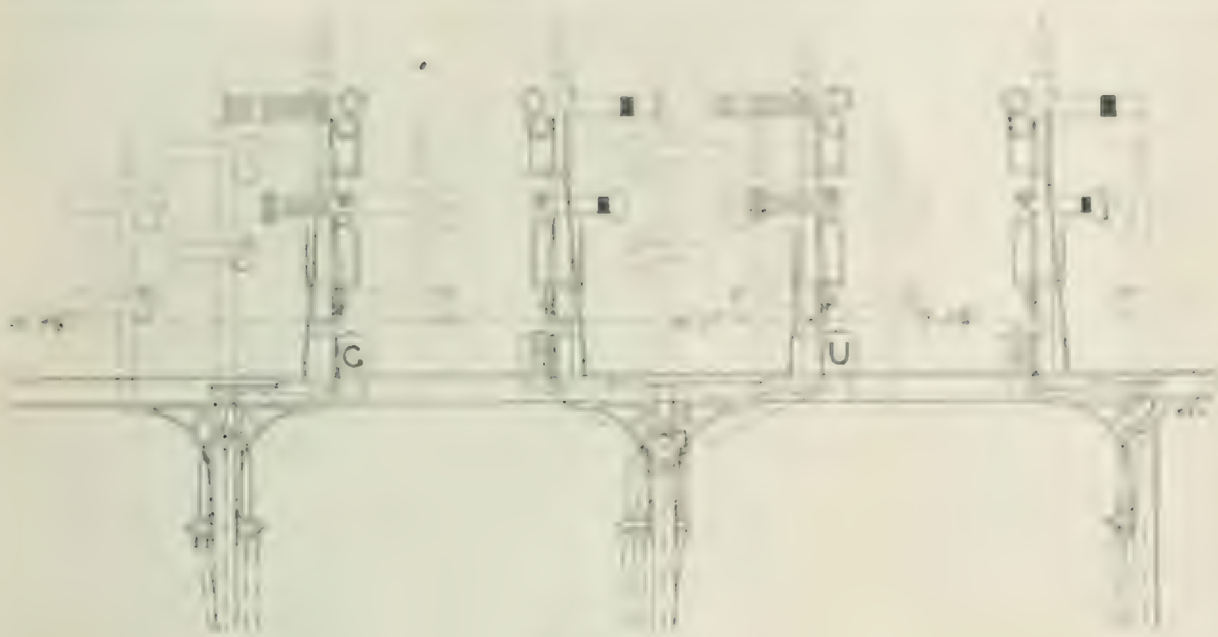


Fig. 6.

Flashlight signals.—On Swedish railways distant signals are provided with flashlights as a distinction from other signals. The flashlight is operated by a diaphragm valve, controlled by a permanent magnet and compressed gas. The flash can be regulated to give 10 per cent light and 90 per cent darkness—or whatever duration is required—and it is claimed that the apparatus is effective; but it must be admitted that a flickering light might be mistaken for a flashlight. Flashlights were tried about 25 years ago in this country and were not adopted, but they are now being tried on one or more of the English railways.

Ground signals.—Ground signals are now generally made of the miniature semaphore type (Fig. 4) in substitution of the disc type. Considerable discussion has arisen lately on the question of the abolition of red lights in ground signals, it being considered desirable to reduce the number of red lights on railways in order to prevent hand signals

[illegible]



[illegible]

"[illegible] out of running loops."

[illegible] stations the number of signals required for entering and [illegible] for which particular road the points are set for the train to [illegible]

[illegible] repeaters more generally to distant signals, [illegible]

the facility with which the latter can be seen, in order to give the signalman an indication of the working of the signal. Home, starting, and other signals are also electrically repeated where they are out of sight of the signalman. These electric repeaters are preferably of the 3-position type, showing "on", "off", and "fault". Where signal lights cannot be seen by the signalman at night-time light indicators, electrically operated on the pyrometer system by the expansion bar placed over the flame of a signal lamp, are also provided in signal-boxes, but are not at the present time generally adopted. It is interesting to note that this device was invented as far back as the year 1866.

In a paper which he read before the Institution of Civil Engineers,* Mr. A. T. Blackall mentioned a device for interlocking the distant signal with the block telegraph system in such a manner that it is impossible for the signalman to give "line clear" to the section in the rear, unless at the time he attempts to do so his distant signal is properly at "danger". This is done by making use of the electric repeater circuit, and ensures that the distant signal must have gone to the danger position after the passing of one train and before the acceptance of another.

Interlocking Apparatus.

High tribute must be paid to the pioneers and inventors of interlocking machines, as this is the fundamental principle of the safe working of the traffic on railways, and the well-known firms of Messrs. Stevens & Sons, Saxby & Farmer, McKenzie & Holland, The Railway Signal Company, Ransomes & Rapier, Sykes' Interlocking Signal Company, and Spagnoletti, have one and all rendered valuable services to the world in the solution of signalling problems and appliances for the same.

The locking frames of the present day may be classified in two types :—

(*a*) Lever frames fixed on the floor of the signal-box with the locking gear fixed above the floor-level.

(*b*) Lever frames with locking gear fixed below the floor-level, the levers being fixed on a fulcrum below the floor-level.

The author favours the former type as being easy to fix, since it is unnecessary to provide a well in the signal-box floor; and it has the further recommendation that the locking apparatus being fixed on the floor can be superseded by a new lever frame with complete interlocking, where considerable locking alterations may be required in the re-arrangement of signals and points, instead of carrying out the locking alterations on the spot, as it is well known that such alterations occupy considerable time and cause much hindrance to traffic during the disconnection of locking gear. In providing a new locking frame of this type it is quite unnecessary to disturb the signal and point connections to the same extent as in a locking frame in which the locking gear and lever centres are fixed below the floor-level, as shown in Fig. 7.

Figs. 8 and 9 show the type of locking frame used on the Midland Railway. The locking is of the tappet type, and the tappets are actuated by the lifting of the catch handle, the movement being conveyed through a rocker to which the tappet is connected. It will be thus seen that no undue force can be brought to bear on the locking gear; and the locking blocks, slides, and tappets are very much lighter, and the parts smaller, than in the case of so-called "direct lever" tappet locking. There is also not the liability of the locking being strained by the usual thrust of the point-rod connection. With direct lever locking, immediately the catch handle is lifted, in the event of the lever being locked, a considerable strain is put on the locking gear, and this is a disadvantage from a maintenance point of view.

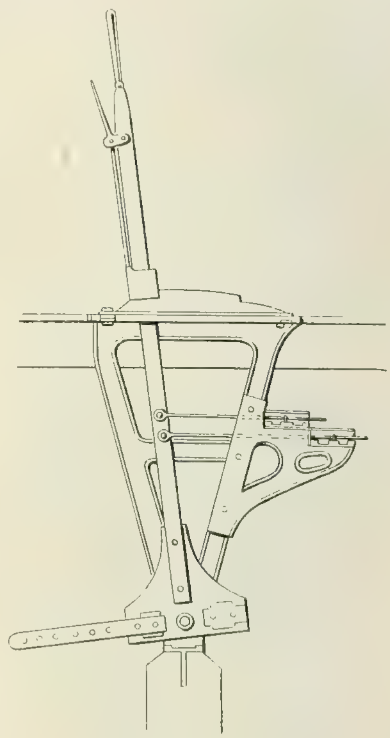


Fig. 7.—Tappet Frame.

Points and Facing Points.

Points, otherwise termed switches, in lines of railways, for turning trains from one line to another, are in manual systems worked with rods or tubes of $1\frac{1}{4}$ in. diameter, supported on travelling rollers in order to reduce the friction in working, spaced from 6 to 8 feet apart, and carried on timber stools or cast-iron trestles sunk into the ground. Cast-iron trestles are, in the long run, very much more economical than timber, as they do not perish in the ground and when alterations to rods are required can be used over and over again, which is not the case with timber. From practical experience the author has found the use of cast iron, both for trestles and crank frames, a valuable method of reducing the cost of maintenance.

Under the Board of Trade requirements trailing points in passenger lines can be worked 300 yards, and facing points 250 yards in manual installations and 300 yards in power installations from a signal-box. The distance for working facing points is restricted to 250 yards with the proviso that the plunger should be detected.

* A. T. Blackall. Railway-signalling: developments on the Great Western Railway. *Minutes of Proceedings of the Institution of Civil Engineers*, vol. 185, p. 153, 1910–11.

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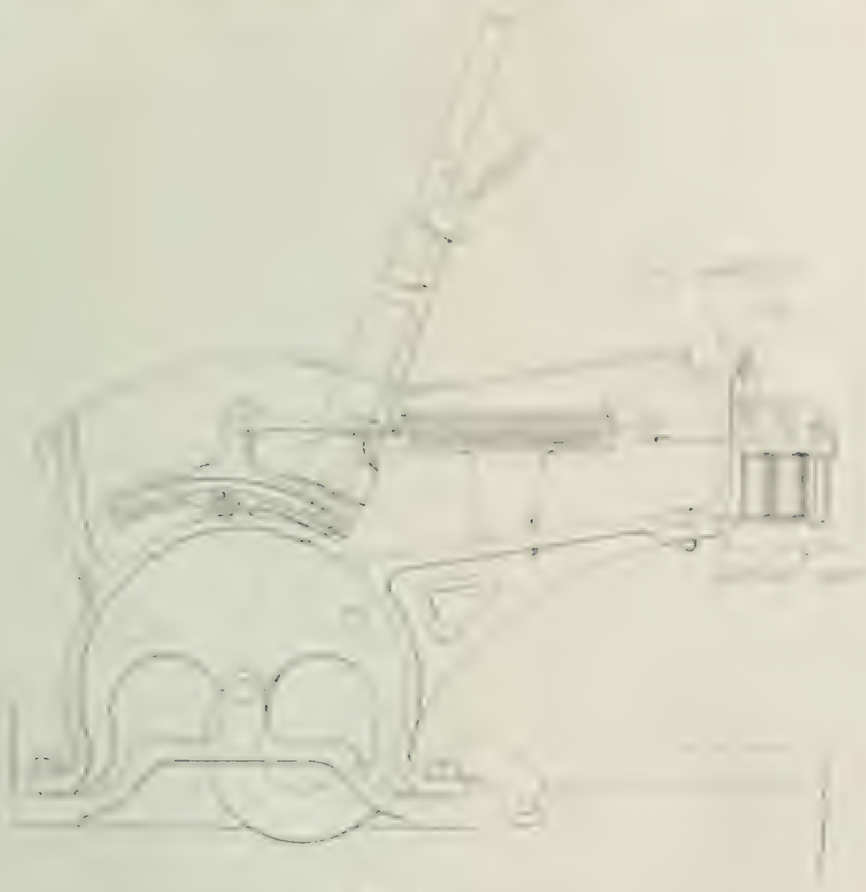


[illegible]

[illegible] enter slots provided in the stretcher rod and prevent any movement when once locked. The motion plate is connected to the locking bar (the latter being of such a length [illegible] the signal-box is conveyed through the locking bar to the [illegible]

[illegible] against the main lines.

[illegible]

running, check, and wing rails is closed up and thus provides a continuous rail on which the wheels can run. The movable diamonds are treated in exactly the same manner as facing points, and are provided with bolt lock and locking bars, also the necessary detecting appliances. This arrangement, however, causes some complications in fixing the gear, on account of the confined space in the permanent way; but in the long run it effects a considerable saving in the wear and tear, and is particularly suitable to junctions laid out for fast running.

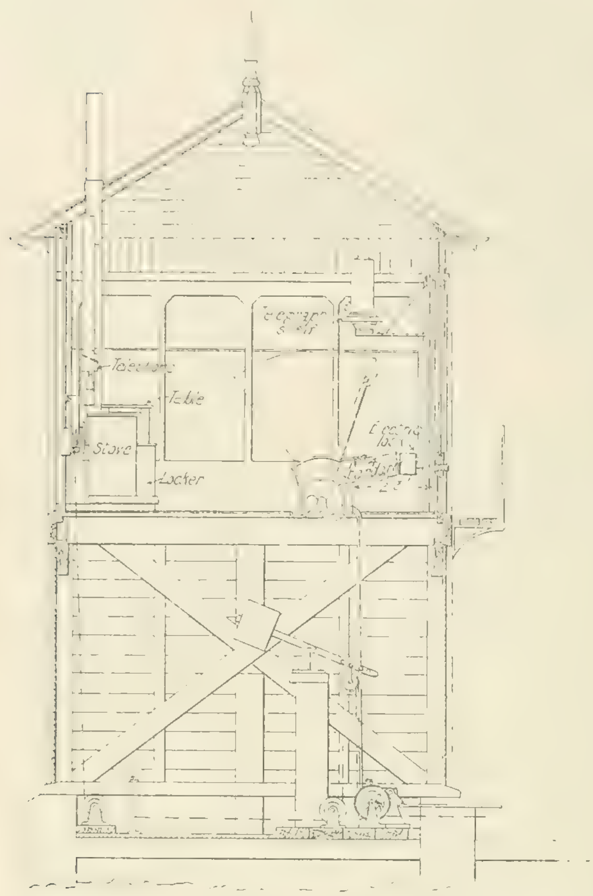


Fig. 9.—Position of Lever Frame and Fittings in Signal-box.

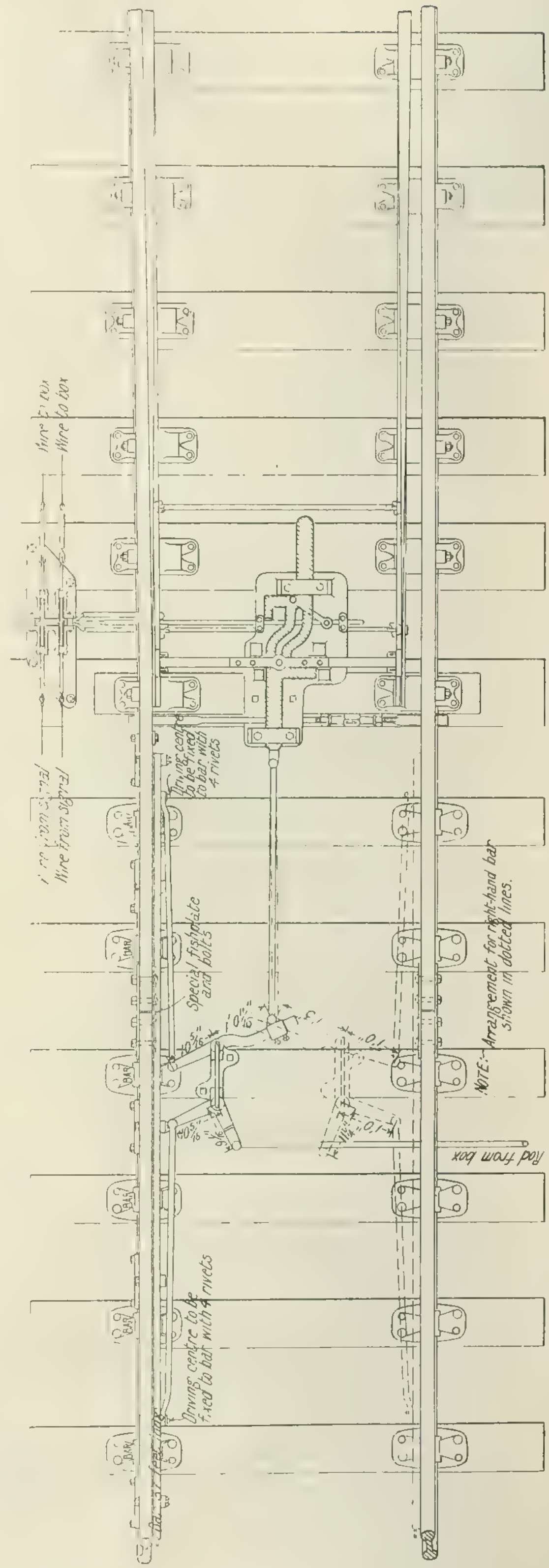


Fig. 10.—Midland Railway. Facing-point Lock.

Interlocking.

To describe briefly the requirements of a locking apparatus:—

(*a*) The interlocking must be so arranged that the signalman is unable to lower a signal for the approach of a train until after the points have been set in the proper position for the train to pass.

(*b* That it shall not be possible for any two signals that might lead to a collision between two trains to be exhibited at the same moment.

(*c*) That after the signals are lowered to allow a train to pass, it shall not be possible to move any points connected with, or leading to, the line on which the train is moving.

(*d*) Points also, if possible, must be so interlocked as to avoid the risk of a collision.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible] to make certain that the rails on the bridge are in proper alignment with those on the abutments. For this purpose signal-boxes are provided, either on the bridges or on each side of the bridges, from which the necessary bolting [illegible] blocked. Mechanical and electrical devices are used, and bolts, resting blocks, wedges, pawls, etc., are properly secured in position. Not only are railway opening bridges treated in this manner, but also important road bridges over rivers, such as the well-known Tower Bridge in London.

[illegible]

The Electrical Tablet system allows signals to be dispensed with at intermediate stations that are not tablet-exchanging stations, and also enables siding connections to [illegible]

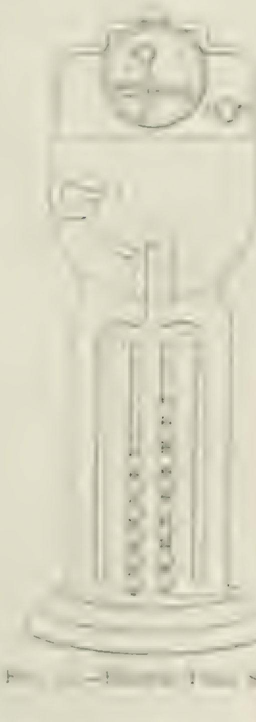
[illegible]

[illegible] special instruments are provided, in which are stored a number of tablets and staffs, which cannot be withdrawn without the consent of the next block section, and upon [illegible]

[illegible]

[illegible]

[illegible] chance of a train starting away without the tablet or staff being taken out.



[illegible]

[illegible]

Switching-out tablet stations.—There are cases where it may be necessary to close certain block sections on single lines where trains are still required to run, and this has been one of the difficulties that had to be overcome. It is effected by duplicating the instruments in the station on each side of the block section that is to be closed, and providing special switching apparatus in that section. In such cases it is only by the co-operation of each of the sections that this method of working can be adopted; but to prevent the possibility of the tablets becoming mixed up, tablets of different configurations are used in the special tablet instruments, and on account of their shape they cannot be inserted in the instruments of the closed section.

Exchanging tablet or train staff.—To prevent the necessity of trains slowing down, devices are in use to enable the tablet or staff to be delivered and another for a second section to be picked up, thus eliminating the risk to the driver or signalman which might occur in travelling at a high speed. One exchanging apparatus is fixed by the side of the railway and the other on the side of the engine, and at a given moment one is picked off the engine and another delivered to the apparatus on the engine.

System without tablet or staff.—This system is so arranged that the block instruments controlling the single-line sections also control the signals for entering the sections, the signals being actually worked electrically by the position of the block instruments, *i.e.* the signal cannot be taken to the off position unless the train is signalled on the block instruments and permission obtained from the section ahead. The signals are of the large "moon" or "banner" type, the arm being enclosed in a circular cast-iron case with glass back and front, illuminated at night.

Reversible Working.

The difficulty of handling suburban-line traffic at terminal stations is one that is experienced by most railway companies, on account of the rush of traffic not being in the same direction during morning and evening hours. Duplicate lines for each direction of traffic is of course the ideal system, but where the surroundings of railways do not allow of this without entailing an enormous expenditure of capital, some means is desirable to cope with the heavy incoming traffic in the mornings and the outgoing traffic in the evenings.

In the case of the three lines approaching the London Bridge terminus of the London, Brighton & South Coast Railway, for a distance of $1\frac{3}{4}$ miles two of the lines were originally devoted to up-train working, and one line to down-train working. At the time when the arrangement was laid out it was thought to meet the traffic requirements, but time has proved that this is not so, since from experience it is found just as essential to have the use of two lines for "down" evening trains as for two lines for "up" morning trains. With the object therefore of increasing the traffic-carrying capacity of the existing lines, a special method of working has been established whereby during the rush hours the middle one of the three lines is used for alternate working as an "up" or a "down" line as the case warrants, to facilitate the dispatch of trains to and from the terminus according to the traffic requirements. The middle line that is used for reversible working is provided with signals and lock and block instruments in each direction, which interlock the signals and point levers in the usual manner, but are so arranged that only one set of signals and instruments can be in use at the same time through the particular length of line, an essential feature being that no train can be in any of the sections when the working on this road is reversed from one direction to the other.

The levers working the signals are interlocked with a master lever, which in its normal position releases the "up" signals and block instruments, and locks the "down" signals and block instruments, and vice versa, the master lever having two locks on the front with latches that enter notches in the quadrant of the locking frame. The keys for actuating the latches are labelled "up" and "down" respectively; the master lever therefore controls the signals, and the keys control the master lever.

In each signal-box instruments are provided containing two key commutating switches, one for the up and one for the down-line working. Into these the controlling keys are alternately placed, it being possible to remove one key only at a time from the master lever, regulated by the locking. The key is inserted in the special instrument, the turning of which frees the corresponding block instrument; the key for the opposite direction of working being locked in the master lever in its reversed position.

There are times in the case of morning "up" traffic when the terminus has all platform roads occupied, and in this condition the middle line then being used for "up" traffic becomes no longer of any use, because the inflow of traffic must of necessity be regulated by the outflow of traffic. It is on such occasions that the middle line can be at once changed over into working for "down" trains, this being one of the chief advantages aimed at for handling the morning traffic in an increased quantity.

Train-stops.

Train-stops for emergency purposes have been suggested by the Board of Trade as a means of arresting trains running past signals at danger. It is comparatively easy to provide them on electrified railways where the speed does not exceed 40 miles per hour, but in the case of steam railways, or even electrified railways where the speed may be anything from 40 to 80 miles per hour, it becomes increasingly difficult to design any appliance of this type that will stand the shock of impact, and at the same time meet with the requirements of express traffic working. Up to the present time it is generally considered that no known automatic train-control apparatus of the mechanical type can be considered to be satisfactory. On the London Electric Railways train-stops and trip valves are in use, and the brakes on the trains are thereby applied when the home or starting signal is against the train. The train-stop is fixed outside the line 8 inches from the inside of the running rail, and projects 3 inches above rail level. In its vertical position it corresponds with the danger position of the signal and works in sympathy with the same, so that when the signal is moved to "clear" by power the train stop is lowered below rail level. The trip valve hangs down from the train, engages with the train-stop in its vertical or danger position, and upon striking the train-stop operates the brake. Upon the train being brought to rest the motorman had to re-set the trip lever before the train could proceed, but further improvements have been made

[illegible]

apply the brake, but in such a manner only that the brake can be released at the desire of the driver to prevent the train being brought to a dead stop.

[illegible] signalling device is the solution of the problem up to the [illegible] the driver, as it is undesirable to provide anything that will distract the driver's attention from keeping a proper look-out as to the condition of the railway ahead, which is one of the many important instructions laid down.

[illegible]

tion to traffic working generally. It is used not only in [illegible] extends.

[illegible] positive manner to denote that the line is "clear" or "occupied".

[illegible] tion of the track [illegible] vibration caused by passing trains.

[illegible] considerable economy is effected by the fact that the [illegible] without any difficulty.

[illegible] current track-circuiting to meet all requirements [illegible] currents, even from an alternating-current power supply.

and in some cases is cheaper to install than continuous-current track-circuiting; moreover, it is said to be easier to maintain, especially on electrified railways.

On electrified railways the track circuits are sanctioned by the Board of Trade to supersede the locking bars on facing points, and the track circuit electrically locks the facing points in whichever position they are set for the trains to pass over, the signal lever governing the route being electrically back-locked until the train has passed the overlap of the section, so that as long as the track circuit is occupied the points cannot be moved until the train has cleared the track.

Platelayers' lorries require special attention where a track circuit exists, and before they are placed upon or run over any portion of a line that is track-circuited the permission of the signalman to whose signal-box the track circuit is connected must be obtained, owing to the fact that lorries cannot be relied upon, particularly if unloaded, to short-circuit the track so that signals are set at "danger", or to operate the electric locking on the signals. A series of rules are therefore essential in order to provide against all contingencies that may arise, and special printed forms should be issued, suitable for all cases, for installing, re-laying, and alterations, which forms should be signed

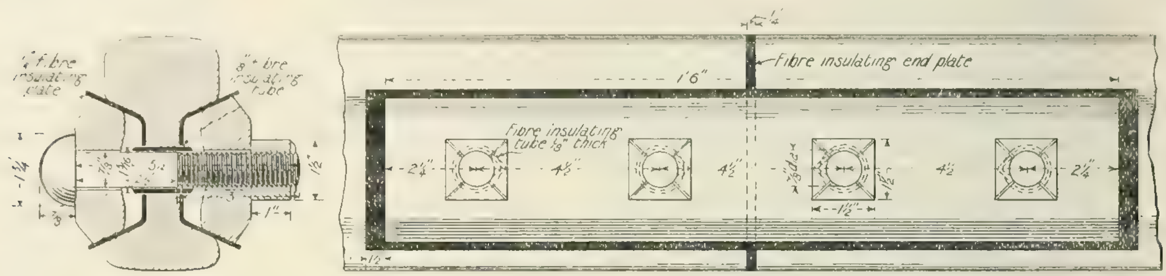


FIG. 13.—Midland Railway, Insulated Joint.

The adoption to any large extent of track-circuiting on steam-worked or electrified railways has necessitated greater co-operation between the permanent way and signalling staffs in maintenance work. It soon became apparent that re-laying or repairs to the permanent way could not, with any degree of safety, be carried out in the manner hitherto customary, such as breaking the road and merely placing flagmen in accordance with the original rules and regulations, because by the insulating of sections of the line the actual running rails become a signal-control apparatus. Thus the action of changing crossing and ordinary rails becomes equivalent to the disconnection of signalling arrangements, and the rules for permanent-way operations and disconnection, although practically distinct rom one another in the past, now become so closely allied that one depends on the other if safety is to be maintained. In the ordinary rule book there is no mention of such appliances as track circuits or electrical locking, and it has been found essential that new rules must be laid down governing such contingencies, as the act of changing running rails necessitates the breaking of rail bonds, which at once throws out of gear the protection given by such an appliance.

Before a track circuit is installed it is very necessary that the permanent-way engineer should be informed, in order that the platelayers may know upon what section track circuits exist. Stringent regulations are therefore necessary to prevent any new track circuit being brought into use, or any alteration made in the length or use of any existing track circuit, without the authority of the general manager or the general superintendent. Even in the lifting or sluing of the line, or performing any operation on a section of line that is track-circuited, the greatest possible care must be taken to avoid damage to wire bonds between the rails, insulated points, underground cables, or the boxes containing the electrical apparatus.

in the names of the responsible persons of the department affected.

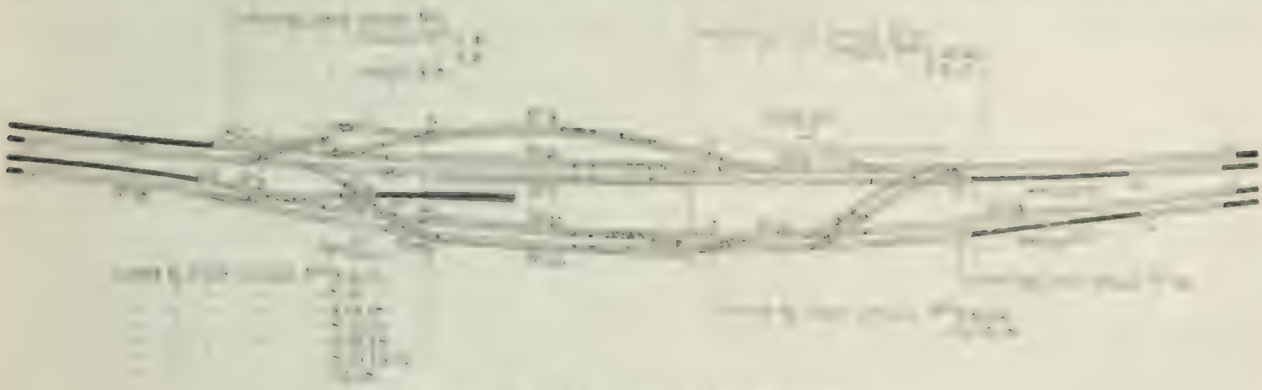
PREVENTION OF ACCIDENTS.

Although railway companies to-day can on the whole be congratulated on the comparatively small number of accidents due to collisions of passenger trains, taking into consideration the enormous number of trains passing over the lines of railways, the accidents of the past few years, however, have been the means of bringing about additional and more improved safety appliances. It is no less a fact, however, that the accidents of late have been of a curiously complex nature, being brought about by a series of small irregularities, the concurrence of which has resulted in disaster. In the year 1913 all the fatal train accidents can reasonably be attributed to errors of judgment or want of care on the part of employees; and it is a matter of some small consolation to signal engineers that accidents have not occurred so much from the failure of signalling appliances in use as from the want of necessary precaution of the operating department staffs in the non-observance of rules laid down, not only for the protection of the travelling public, but for the individual staffs of all railway companies.

One of the most generally discussed rules, the non-observance of which has been the cause of frequent accidents, is the notorious Rule 55. This rule is referred to and quoted by most journals, newspapers, and technical papers, and is one to which railway companies are giving much attention, and which in recent years especially has been amended, whilst large sums of money are being spent in installing appliances for the protection of trains detained at home or starting signals.

There is little doubt that this rule has in a measure not been strictly observed, and attempts have been made to find out why there has been the relaxation in its application. It is now realized that this rule can no longer be

[illegible]



[illegible]

[illegible] instrument remains locked in the train-on-line position [illegible] has operated an electric treadle ahead of such signal, the [illegible]

[illegible] at home signals out of sight of the signalman. In this case a short length of track circuit is provided, outside the home signal, which indicates the presence of a train and [illegible]

[illegible] visual indication of the condition of the line to [illegible] on to that line, thus preventing the [illegible]

[illegible] routes.

[illegible] shown etched, and the lines not so treated [illegible] parallel movements either on the str[illegible] the junctions. According to the sub[illegible]

traffic. It will therefore be seen that track 5 locks the "up" fast home and "up" fast to slow home signals, whereas track 6 locks the "up" fast home signal and also the "down" home signal from slow to fast lines. Again, with Nos. 13 and 15, it will readily be seen that if the other tracks are not stopped off, a train passing over these subdivided tracks would lock signals for opposite movements on other lines, to the detriment of the traffic-working.

The arrangements therefore provide for a continuous track circuit between the home and starting signals, although this may be subdivided where necessary.

In cases of less important lines, where it is considered unnecessary to incur the expense of track circuits, they are met by providing a treadle ahead of the starting signal and an electric lock on the home signal, so that after the home signal has been lowered and replaced to danger it becomes locked in its normal position until the treadle ahead of the starting signal has been operated. Special mechanical locking is provided on the levers working these signals so that it is necessary for the home signal to be restored to danger before the starting signal is replaced; and similarly the starting signal has to be replaced to danger before the home signal can be used again. This

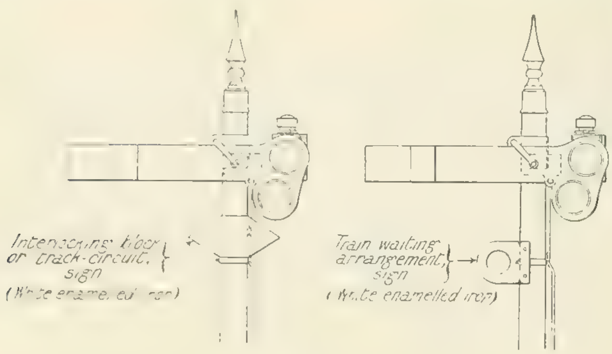


FIG. 15.

arrangement, in conjunction with the interlocking rotary block, ensures the signals being at danger before another train can be accepted on the block instrument.

Train-waiting arrangement.—This is an audible and visual system, and enables a fireman to inform the signalman that his train is waiting at a signal where it is undesirable that he should go to the signal-box to carry out Rule 55. A plunger and an electric horn are fixed on a cast-iron column near the signal, and, on the arrival of a train at the signal, the fireman alights, presses the plunger, and in so doing operates an audible buzzer in the signal-box and causes an indicator to show "train waiting". In addition the block instruments are locked, and the needle turned to the train-on-line position, no matter what indication was there before. The electric horn at the signal denotes to the fireman that these operations have been carried out, but does not call for any acknowledgment on the part of the signalman, as it is considered undesirable to require the signalman to carry out any operation at this stage. The signalman cannot remove the train-on-line indication from his or the rear-box block instrument until he has pegged his instrument to "train on line" and then pulled over and replaced the home signal to danger. Some companies in using a somewhat similar appliance provide illuminated lamps where such apparatus is installed, but from experience these have not been found necessary.

Signs and indications of exemption from Rule 55.—With the introduction of appliances for the protection of trains detained at signals, as before mentioned, it has been found necessary to provide some distinctive indication on home and starting signals at which the carrying out of Rule 55 is dispensed with. At first it was thought sufficient to publish, in the weekly traffic notices issued, a list of signals to which such exemption applied; but the list became of such great length that it was deemed unreasonable to expect the staff to commit the same to memory, and so two distinctive signs were introduced, viz.

(*a*) A diamond-shaped sign, as shown in Fig. 15, indicating that the train standing at the signal is protected by interlocking rotary block, track-circuit, or treadle arrangement.

(*b*) A D-shaped sign, as shown in Fig. 15, indicating that means are provided for trainmen to protect the train by their own efforts by pressing the plunger of the train-waiting appliance, previously described, fixed on the ground at the signal at which the train is detained.

About 1,200 signals on the Midland Railway are provided with these signs. Other companies are adopting them, and it is hoped that the practice will become universal.

Prevention of drivers running past signals at danger.—Some of the most serious accidents in recent years have been brought about by drivers disregarding signals and thus overtaking other trains, or causing their trains to be derailed owing to excessive speeds over sections of line where speed restrictions are in force. This could be more readily understood if such behaviour on the part of the drivers was only during foggy weather before fog-men are called out, but unfortunately accidents due to this irregularity have occurred in perfectly clear weather.

Detonator-placing machines are now used to a very considerable extent to enable the signalman to comply with Rule 85, which states that:—

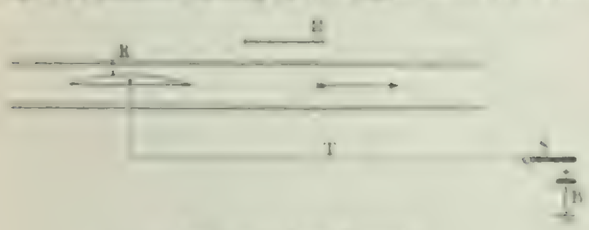
"At all signal-boxes (whether intermediate or otherwise) where no fog-signalmen are appointed, or where such men are appointed but have not arrived, the signalman, when he requires to stop an approaching train, in addition to keeping his signals at danger, must, when practicable, place detonators on the line to which the signals apply."

The detonator-placing machine is sometimes placed a few yards inside the home signal, and is connected to the wire working the signal. In other cases it is fixed opposite to, and worked by a separate lever from, the signal-box. About 600 of these appliances are in use on the Midland Railway and have been the means of effectively arresting runaway trains. The times, however, call for a more effective and permanent appliance that will be in operation at all times and for all trains; and this subject is receiving considerable attention.

In finding a solution of this problem it is realized that there are serious obstacles to be overcome, the first of

[illegible] requirements.

[illegible]



[illegible]

approaching a distant signal which is at danger, and, in the event of this warning being disregarded by the driver, auto- [illegible] distinctive audible signal is also given on the engine when [illegible] the latter audible signal is that it facilitates the running of trains when the semaphore signals cannot be seen during [illegible] of a siren, indicating "stop", and the ringing of a bell, indicating "proceed". The point at which the [illegible]

This apparatus involves a metal ramp, about 60 feet in length, fixed in the centre of the 4 ft. way of the railway, [illegible] train passes over it the [illegible]

[illegible]

[illegible] is to cut out or render inoperative the switch attached to the shoe, so that although the switch is opened it does [illegible]

in connection with electric train staff and tablet systems by certain modifications.

Several cab-signalling devices have been brought out from time to time, but complications have been introduced by the inventors attempting to do too much in indicating signals other than distant signals. It may be laid down that two of the most important functions of such appliances are, first, any failure of the apparatus should be on the side of safety, and give a danger indication to the driver; and secondly, "clear" indications as well as danger indications should be given, with the object of avoiding unnecessary delay to trains.

The problem of cab-signalling on electrified railways is rather a different matter and one which requires much consideration, as the space available in the 4 ft. way is very much curtailed in third-rail systems, owing to the fact that the negative rail is placed in the centre of the 4 ft. way, and consequently the ramps would have to be fixed between the negative rail and one of the running rails. There is every reason to suppose that the shoes would have to be duplicated so as to suit the reverse running of trains, both on single and double lines. The possibility of such an apparatus being affected by extraneous currents is another point that would call for special consideration.

Railophone.

This system, an invention of Mr. H. von Kramer, as applied for giving an automatic warning in the engine cab of the vicinity and indication of a signal, differs from anything up to the present actually tested and offered to railway companies. The system is undoubtedly designed on right lines, and may be said to mark the latest phase of electrical operation. It is primarily intended for use in connection with distant signals, with the object of giving the desired warning of the position of the signal arm and causing the train brakes to be applied automatically when occasion requires, should a train overrun a signal.

Unlike the automatic train control previously mentioned, this system has no physical connection or contact with either the rolling stock or the permanent way, but is operated entirely on the wireless inductive principle, the transmission of electrical energy being between a fixed circuit on the ground and a circuit placed on the moving train.

The stationary circuit consists of an insulated conductor, laid in the ground some feet away from, but parallel with, the track. The train circuit consists of a large electric coil mounted round the engine, and there is no actual contact of any description between the train and track. The fixed circuit is supplied with alternating current at a predetermined frequency (say 100 periods per second), which cannot vary more than 2 per cent up or down. The coil on the train is connected to a K.K. relay, which is the essential and distinctive part of the whole scheme. This relay is the joint design of Dr. Gisbert Kapp and Mr. Kramer, and is so tuned as to respond only to the frequency for which it is set. A local relay circuit, which makes all the necessary indications and controls, is joined up with the vibrating armature reed of the K.K. relay in such a way that it is only when the relay reed is vibrating that the local relay circuit is completed. This makes the apparatus a positive safety one, as if anything happens to the fixed circuit, or to the train coil, or to the relay, it will be seen that the relay reed ceases to vibrate; the local relay circuit is then broken, and the necessary danger operations are carried out.

An experimental installation has been tested on the Midland Railway, but so far it has not been considered desirable to publish any results. It may, however, be interesting to note that a driver on approaching a distant signal receives three short warnings in quick succession by means of a compressed-air whistle fitted in the engine cab, quite irrespective of whether the signal is at danger or clear. Should the signal indicate danger, the three warning signals are followed by a fourth prolonged signal, and the brakes are automatically applied, but it is so arranged that the fourth signal and the application of the brakes take place only if a driver fails to apply the brakes in the ordinary way after the three warning signals have been received. Should the signal be in the clear position the train is allowed to proceed without interruption, but the driver is aware that he is passing a signal by the three warning signals given on the whistle.

Electrically-controlled Signals.

The controlling of signals by electric slots and replacers was first introduced in lock-and-block installations with the object of automatically placing to danger the starting signal for entering the section ahead, irrespective of the lever in the signal-box being placed to its normal, or danger position, this being done by means of treadles, and the apparatus so constructed as to render it impossible to lower the starting signal a second time unless the lever was put back in the signal-box and "line clear" received from the section ahead.

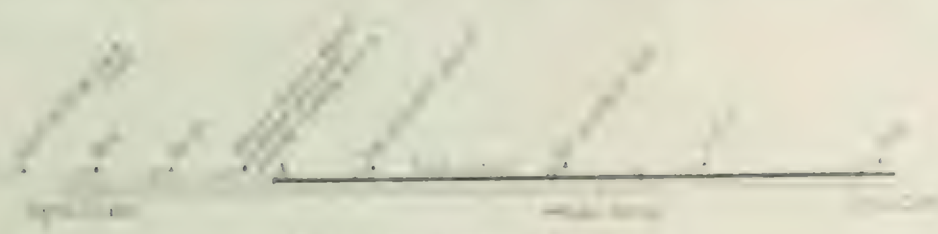
Electric slots and replacers are fixed in the rod working the signal arm, and in some contrivances the replacing gear is fixed on the spindle working the arm; in each case the engaging is effected by energizing an electromagnet which holds an armature or pawl in position, allowing the signal to be lowered by the pulling of the lever in the signal-box.

Electric Selectors.

In cases where a calling-on arm or draw-ahead signal is fixed under a right-away signal, either for entering or leaving a platform line, a considerable saving in working levers of manual systems can be effected by the use of the above appliances, and allows of additional signals being provided without introducing extra levers.

The condition of the line ahead determines whether a clear or draw-ahead signal shall be given by means of track circuit or electric fouling bars, the former being preferable for train protection. Although there is some difference of opinion as to the advisability of providing track circuits in terminal platform roads, the author suggests from experience that it is practicable if rails are kept clean. The upper arm is free to be lowered so long as the track circuit or fouling bars are unoccupied, otherwise the electromagnet or the selector is de-energized, and the bottom arm then only can be lowered; but the signals controlled by this appliance are not usually placed to danger automatically.

[illegible]



[illegible]

Fig. 18.—Semi-automatic Signalling.

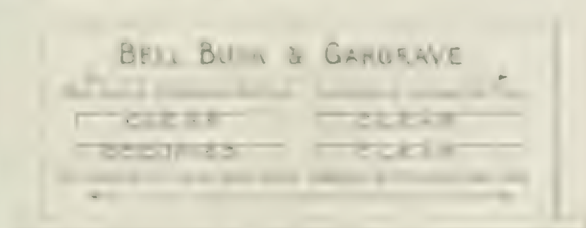
[illegible] dealing with the problem, viz.

(a) [illegible]

(b) By making the semi-automatic signal act as an outer home signal to the advance section (see Fig. 18), in which case the ordinary block system between the rear and advance signal-boxes is dispensed [illegible]

[illegible] former, inasmuch as a train entering the semi-automatic [illegible] the track circuits are divided up, and in order to comply [illegible]

which upon being pulled over [illegible] for a train to leave that section.



[illegible]

closing a contact in the signal circuit. The signal circuits are so arranged that when it is unnecessary to operate the points, the signal levers may be and are generally left in the reverse position; the signal control is then governed solely by the track-circuited lines to which the signals apply and becomes entirely automatic, thus enabling block or lock-and-block instruments to be dispensed with. This has the merit of enabling existing signal-boxes and locking frames to be retained, where necessity arises, when installing automatic signalling on steam or electrified lines, and very considerably reduces the cost of installation, as against "scrapping" existing locking frames and providing power frames working points. It thus places the reconstruction of signalling systems within reasonable reach of railway companies at a comparatively lower cost of expenditure.

Automatic Signalling.

The object to be attained by the use of automatic signals, unlike that of manual block signals, is to compel a signal being put to danger behind each train on a double line of railway, and cause it to remain in that position until the train has gone a certain distance beyond that signal. In the case of single lines the same object is attained, with the addition that at all times a signal governing movements in the direction opposite to which the train is moving must be displayed in the danger position some distance ahead of the train.

Automatic signalling is an admirable substitute for the block system, the signal movements being governed by electric or pneumatic agency, controlled by the passage of a train into, through, and out of the block section to which the signals apply, this being effected by the action of the train alone operating the track-circuited sections of the lines controlling such signals, the ideal arrangement of automatic signals being such as to secure the maximum capacity for train movements over a given length of line, bearing in mind the effect of gradients and curves on the traffic. Speaking generally, it may be considered that two systems of automatic signalling are used, viz.

(*a*) Normally danger.
(*b*) Normally clear.

It must be admitted that both systems have their good points, and the question as to which is the more suitable is one that has been the subject of much discussion and controversy in the past; and even to-day there are some who favour the former system.

The normally danger system, in which the signal stands continually at danger except when trains are required to pass along the line, agrees with the normal position of a mechanical or manual system, and complies with the standard practice of the block regulations as laid down for traffic working. After being placed to danger by the train entering the section, the signals remain in that position until they require lowering for the following train, this being done by the approaching train lowering the signals if the section ahead is not occupied for traffic in the same direction. This system necessitates greater complications in the electrical connections, as the track circuits have to be so arranged as to lower the signals in addition to replacing them to danger. There is, however, one claim that has been made in favour of the system, viz. that platelayers at work on the line are warned of the approach of a train by the lowering of the signal arm, where the same security is not afforded by a signal standing in the normally clear or "off" position. Experience has proved, however, that there is not as much in this contention as might appear on first consideration.

In normally clear systems the entering of a train into the track-circuited section places the signal in the rear to danger, and the clearing of the block section, by the passage of the rear wheels of the train out of it, resets that signal to the clear position, ready for a following train in the same direction to approach. Those in favour of this system contend that the electrical connections are fewer and more simple, and from a maintenance point of view less costly. There is much to be said in favour of the normally clear system, because, after all, automatic signals differ considerably from mechanical or manual systems, as they simply indicate to drivers that the section or sections ahead are clear and are an indication of the condition of the line ahead.

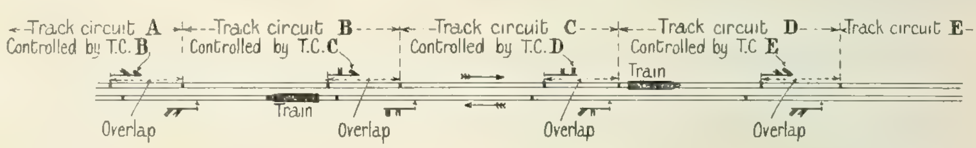


FIG. 20.—Automatic Signalling.

In all automatic-signalling installations there is the risk of trains being unduly delayed at signals in the event of failure of the apparatus, in which case the signal would remain at danger. To provide against such a contingency it is customary to allow drivers to pass the signal in the danger position after coming to a stand and waiting a prescribed time, as laid down in the rules and regulations of working. After starting again the driver is allowed to proceed cautiously, being prepared to stop at or before reaching the next signal. If the next signal is at clear he may proceed at regular speed until reaching the next signal at danger.

Fig. 20 shows an arrangement of automatic signals for one road on a double line of railway. Single lines of railway can be worked by means of automatic signalling instead of by train staff or tablet systems, but up to the present the author is not aware that such an arrangement is in use in this country.

Overlaps.

These consist of an extension of a track circuit from 100 to 440 yards ahead of a signal, such track circuit and its extension, when occupied, securing the signal in the rear at danger.

Overlaps are used to guarantee that a space is provided

[illegible]

[illegible]

[illegible] unnecessary to weight the arm in order to ensure it return- [illegible] and if any breakage occurs the failure is on the side of [illegible] through a rod breaking, the Board of Trade enforced the [illegible]

The 2-position upper-quadrant signal practically performs the same functions as the ordinary arm.

A [illegible] giving "danger" in the horizontal, "caution" at an upward inclination of 45°, and "clear" in the vertical position; and provides for the abolition of the distant signal altogether. It has yet to be proved whether such a measure is justifiable, or will meet the requirements of very busy lines, particularly in long sections, or sections on electri- [illegible] used with the object of speeding up the traffic where trains are delayed longer at one station than another, due to the extra time taken in loading up and discharging passengers.

There are cases on the underground railways in England where inner and outer stop signals, and sometimes a second outer signal, approaching stations, are placed comparatively close to one another, thereby allowing an [illegible] train standing at or leaving the station protected by these [illegible] prevent such close working and would delay rather than expedite matters.

Up to the present time 3-position signals cannot be said to have been actually put in use on English railways. As before stated, this type of signal is intended to supersede the use of distant signals, and in short sections, not exceeding 800 yards, would enable the traffic on a railway to be worked satisfactorily; but where sections are of a greater [illegible]

[illegible]

[illegible]

[illegible]

The purpose of signal lights is to afford the most distinctive indication possible at the maximum range required [illegible] open question whether yellow lights are a solution of the [illegible] in 3-position signals, yellow, red, and green.

[illegible]

[illegible] containing red or yellow and green lenses, one above the other, electrically illuminated, the lamps being controlled [illegible] relay is de-ene[illegible]

This form of signal is being used not only in tunnels but [illegible] that the lights may be discerned at long distances. So far the author is not aware that lamp signals have been used in this country for traffic at high speeds, and experience [illegible] daylight, particularly on curves, because in brilliant sunshine the lights are bound to be dimmed, even if hoods are provided over the top and sides of the lights. It would appear easier for drivers to locate a semaphore arm than a [illegible]

[illegible]

engine-miles run. Thus, it is stated that in 1908 on a percentage of a total mileage of 23·83 there were 26·21 accidents, whereas in 1912 the percentage of total mileage was 30·95, and the percentage of accidents 6·67. In the former case there were 2,324 miles of track with automatic signalling, and in the latter 3,216 miles. It is a difficult matter, however, to compare these figures with those of accidents on English railways, because it depends very much as to what is included under the heading of accidents, but it would appear that English records are better for 1912, because, taking the Midland Railway as an example, 46 million train-miles were run and 26 collisions between trains occurred, this representing only 0·6 collisions to every million train-miles run, and therefore showing greater safety of working, compared with the figures quoted in the statistics relating to American railways.

Power Signalling.

This is a means of operating an interlocking system of points and signals by some form of power other than manual, in which levers for moving points or signals by levers, rods, and wires, are supplanted by levers or slides which close or open valves or electric circuits. The levers or slides are small and are placed close together, so that the length of locking frames and signal-boxes is at once reduced, and they can be placed in confined places, without disturbing the lay-out of the roads in large stations or yards. Consequently they do not call for additional expense in land as against what would be required in manual installations.

The question of power-working at small stations on ordinary railways is hardly worth considering on account of the extra cost of the same, but in large manual signal-boxes where there is a constant succession of train movements, the labour performed by signalmen is very heavy, and as power-working imposes no physical exertion on the part of the signalman the work is necessarily easier. At the same time, although some writers have gone so far as to say that one man working a power frame can do the work of three with an ordinary fame, it is a debatable question whether a signalman can attend to many more roads and signals in a power system than in a manual one, as it is more a matter of mental concentration than muscular exertion, and it must be admitted that in all mental work there is a limit of possibilities. There are, however, many advantages in power-working as against other methods, as several sets of points can, if necessary, be operated by one lever, and more than one signal can be operated per lever by the aid of a selector arrangement, so that on the whole the total number of working levers can be very materially reduced.

There is a further advantage attained in relation to facing points, as the Board of Trade requirements in regard to the maximum distance for working the same by power have been relaxed, this distance being extended to 300 yards from the signal-box. This concession alone is most helpful in the laying out and planning of works, and thus recommends itself to railway engineers.

The essential features of a power system are that the operation of all points and signals, etc., must be ensured, and that the possibility of any movement not being completed must be guarded against. All operations by power are distinctly different in practice from manual operations, because in power systems there is nothing to tell the signalman, by the sense of touch, that an intended movement of any mechanism has been satisfactorily completed. Whereas with manual systems the power exerted guarantees that at any rate a portion of the movement has been attained by rigid connections in the case of points and facing-point locks or bolts and the wire connection to signals, all of which can be regulated by mechanical means as required.

This particularly applies where outlying points are worked from ground frames, controlled by rods from a signal-box, in which case the control or locking is to all intents and purposes reciprocal. In power systems, however, this is not so, and in order to get the same result the locking in one direction must be counter-locked in the other direction. For instance, the fact of releasing a bolt lock on a ground frame does not prevent the lever effecting the release being replaced; and therefore the lever in the ground frame thus released and working the points must in a like manner operate a back-lock on the lever in the signal-box. Detection of signals and points is, however, easier and more elastic than in manual systems on account of the absence of the regulation of wire connections, and lends itself to overcome many difficulties experienced in the manual system.

Electro-pneumatic System.

A large number of signal-boxes have been installed in England, and the largest installation is stated to be that at the Glasgow Central Station of the Caledonian Railway. It consists of 338 working levers controlling 112 points and 245 signals, and it is needless to say that this installation has proved its value. The levers in the locking frame, after being moved sufficiently far to operate the points, cannot be moved completely over, owing to a stop termed a "check lock", which is electrically removed when the points have gone properly over, after which the lever is free to be moved over completely. The mechanical locking of the tappet type then allows the necessary signal levers to be pulled over. If for some reason due to the points not working properly, the point lever cannot be moved right over, the signals for the particular route cannot be lowered. A somewhat similar arrangement is provided on the signals, and compels the signal being properly placed to danger before the signal lever can be restored completely to its normal position. The signalman is thus advised of any failure due to the signal not going to danger, and locks up the apparatus so that further movements are impossible.

In the earlier type of locking frame, handles turned to the left or right were used, but in English practice small vertical levers pulled over as in manual systems are provided, it being considered more consistent with the usual practice in this country.

The mechanism for operating the points is placed outside the 4 ft. way, and consists of an escapement bell crank, the plain end being connected to the stretcher rod of the points, and the escapement end operated by means of a slide with a projection or roller connected to the piston rod. Air is admitted to the cylinder at one or the other end and gives the necessary movement to the slide operating the bell crank, which is also connected to the locking bar. The total movement of the slide produces three distinct

except when the circuit is o[illegible]

signalman is advised [illegible]

[illegible]

from one signal-box to the next by means of bell code or

[illegible]

In view of the perfected electric motors now in use,

[illegible]

the signals [illegible]

[illegible]

operated, and should any points be moved or interfered with by accident or design, the signal circuits affected by the position of the points cause the signals to go to danger, if off, or to be held at danger as the case may be.

A great advantage of the constant-detection principle, although the system is perhaps more costly in installation, is that it enables a failure of detectors to be easily located, and thus saves much running-about on the part of the signal fitters and consequent loss of time. From the experience of others it may be contended that this method is preferable, as most troubles can be located in the lever frame in the signal-box instead of having to be sought for on the ground. This perhaps will appeal generally as one of the vital points of power signalling, as electricity is doubtless the coming motive power for operating points and signals.

All-electric System with Dynamic Indication.

This interlocking system is a somewhat novel departure from other systems of power-worked installations as regards the means of detecting in the locking frame the normal and reversed positions of the points, in order to make certain that the movement of the points corresponds with the position of the lever in the signal-box.

The stroke of the lever is divided into two movements. The first movement locks all conflicting levers and operates the point mechanism ; but in the second and final movement the stroke of the lever can only be completed when the point mechanism has done its work in operating the points. This final movement can be made after, and only after, the dynamic indication has been received certifying that the operated function has assumed a position corresponding with that of the lever in the signal-box.

When the points are to be operated the first movement of the stroke of the lever in the signal-box permits current to flow to the motor, thereby causing the mechanism to move the points to the opposite position and lock them in that position. When this movement has been completed, the circuit through the switch motor is automatically changed, the motor being disconnected from the battery and connected in a closed circuit including the indication magnet. At the same time the armature terminals are reversed for indication purposes, this leaving the motor connections in the proper position for the next operation. The motor now becomes a dynamo, and with the momentum acquired during the operation of the point movement generates a momentary current which energizes the indication magnet, this permitting the final movement of the lever in the signal-box to be completed, releasing such levers hitherto locked. The movement of the points can be reversed at any portion of the travel by the operator at will, and the lever movement completed upon the points assuming a position corresponding with that of the lever, irrespective of the direction of the first movement made by the lever.

The complete point operation, and the final movement of the lever, can be accomplished in from 2 to $2\frac{1}{2}$ seconds, the indication being practically instantaneous with the completion of the point operation.

The indication that the points have moved correctly is given by a current generated by the momentum of the motor, and can therefore be obtained only after the actual operation of the point mechanism, no additional power being required for the indication that the points are properly set to allow of the required signals being lowered to give permission for a train to proceed.

The author wishes to take this opportunity of acknowledging much valuable assistance in collecting matter and preparing illustrations for this paper from the signal engineers of the various railways, Messrs. Saxby & Farmer, Ltd., The McKenzie, Holland & Westinghouse Power Signal Company, Ltd., The British Pneumatic Railway Signal Company, Ltd., The Railway Signal Company, Ltd., W. R. Sykes' Interlocking Signal Company, Ltd., and members of his own staff.

Discussion.

Mr. Hurst.

Mr. A. Hurst : It will be gathered from the paper that not only has a railway signal engineer to be acquainted with mechanical and electrical work and appliances but that he has also to provide what is required to expedite and get traffic over the lines without sacrificing safety ; his work is therefore largely ruled by facts, often of very opposing kinds. For example, the signalling of a line for goods traffic would require the signals to be placed at certain points at such distances apart as would accommodate the length of a train, and at other points so that sufficient distance is allowed to bring the train to a stop before reaching the next signal ; but such distances would be unsuitable for express trains which are fitted with powerful brakes and can therefore stop in shorter distances, and moreover the length of such trains being less the space between certain signals could be reduced as compared with that necessary with goods traffic. Signals have therefore to be fixed to accommodate the maximum length of trains, somewhat to the detriment of express trains. The author has shown in Fig. 6 how letters or figures are sometimes used in conjunction with a single signal to indicate the various routes which may be taken by a train. In a case with which I had to deal, such an arrangement became absolutely necessary because the number of signals was so great that it was impossible to include them all within the width of the railway, with the result that both letters and figures were used. There were seven lines leading into and out of an important station, which were lettered A, B, C, D, E, F, G, of which A, B, D, F, were incoming, and C, E, G, outgoing lines, E and G being also incoming lines for a short distance near the station end. The driver of a train coming along line B, for example, would receive under the signal referring to that line an indication whether the train was to proceed along B line or to cross over into D, E, F, or G lines. In a similar manner at the next signal he would receive an indication in the form of a number showing into which platform the train was being sent. In this case both letters and numbers are used for the same train, in nearly the same way as that shown by the author. It sometimes happens that it is impossible to erect signals in the best positions ; some supplemental device has then to be introduced in order to get over the difficulty. One way is by the use of locking bars. Suppose that a junction is situ-

[illegible]

for track circuits I certainly feel safer when travelling on [illegible]

character of the paper dealing with practice rather than [illegible]

the provision of these, but I do not altogether agree with the [illegible]

reduce their speed for the turn-out ; this is done automatically if there if no distant signal, the one distant for the [illegible]

[illegible] alteration is I think a retrograde movement. In common with the Great Northern Company, the Great [illegible]

[illegible]

I know that certain co[illegible]

[illegible]

quite conceivable that in certain cases the train may [illegible] just clear of a track and th[illegible]

[illegible]

fixing it at the cabin end a [illegible]

saved. On page 775, Fig. 14 illustrates the arrang[illegible]

[illegible]

the outer home signals right through to t[illegible]

[illegible]

the saving in the cost of the overhead wires of [illegible]

[illegible]

Mr. Bound fore appears more a question of providing full braking distance between the distant signal and the stop signal. This, I believe, is the practice throughout the automatic sections on the London & South-Western Railway and also generally in America. By dispensing with over-laps the wiring is simplified and use can be made of a polarized track relay for the clearing of the distant signals, thus reducing the amount of wiring between signal and signal to a minimum. On page 781 reference is made to 3-position signals. I am afraid the author has rather a poor opinion of these signals, as in the first case he states they would prevent close working in short sections, whilst a little farther on he states that where sections are over 800 yards it is feared that difficulties will arise. This therefore apparently restricts the use of these signals to sections of about half a mile. I think the author is unduly nervous; I have recently looked into this question somewhat closely, and I think that the 3-position signal will do all that is now done by the 2-position signal and also a good deal more. The Great Western Railway engineers claim to have had the first 3-position "signal" in use in England, but I hope to show later, on behalf of the Great Central Railway, that my company was the first to introduce 3-position "signalling" in this country. I should like to refer back to Fig. 20, the lower half of which appears to indicate a 3-position signal scheme, but I cannot trace any reference to the same in the context. The signal on the extreme left is clearly a 3-position upper quadrant signal in the 90° position, but that on the right is an ordinary distant signal arm underneath a stop arm, and as this appears somewhat unusual I shall be glad if the author will explain what is intended. On page 783 pneumatic signalling is referred to. There are on the Great Central system 19 cabins worked on this system, all of which give the utmost satisfaction. The most recently installed is the one at the London-road terminus, Manchester. This particular installation deals with very heavy traffic and I think I am justified in saying that the results have been excellent, as our failure record in six months consisted only of two, one of which was attributed to sand, so that whilst the working is greatly facilitated the delays are inconsiderable. In conclusion I should like to refer to the "all electric" system of signalling with the dynamic indication. We have recently installed six cabins having this type of signalling, totalling 372 levers. This installation is, I think, so far the only one of its kind in this country. It has been in use now for about two years and has given very little trouble. One of the chief surprises to me, approaching the subject as I did a firm adherent of pneumatic signalling, was the low cost of operation. For 1 kilowatt-hour about 500 point and signal movements can be made, so that it can readily be seen that with current at a cheap rate, say 1d. per unit, the cost of operation is hardly worth consideration. As far as the system itself is concerned, I think it is on the lines which will be justified by the test of time. One of the criticisms usually made in regard to electric interlocking is the possibility of stray currents, etc., giving false indications, but in this particular system the indication as its name implies is produced through current provided by the over-run of the motor on the completion of the movement, and no other source will give this indication. There is therefore no fear on this head or from contacts being improperly made, where the indication is obtained from a battery located at the same end of the circuit as the indication magnet itself. Mr. Bou

Mr. C. M. Jacobs: My experience is that track-circuiting cannot be relied upon to give "broken-rail" protection. I suggest that it is possible that light vehicles might not effectively short-circuit such short track circuits as those shown at the junctions in Fig. 14, and I should like to know whether the author absolutely relies on the track circuits in such cases to give fouling protection. Mr. Jaco

Mr. C. S. Snell: With reference to the author's remarks on page 777 in regard to automatic train control and audible signals, the audible signals given are the sounding of the siren indicating "stop" and the ringing of a bell indicating "proceed." The point at which the audible signals are given is usually about 400 yards before the distant signal is reached. Now owing to these audible signals being given at such a distance from the distant signal, there is, in my opinion, rather a tendency to confuse the driver under certain circumstances. For instance, supposing he receives a sounding of the siren (indicating "stop") on passing the point 400 yards before the distant signal, the signal is pulled "off" in the time required to travel up to it and the driver sees it at "clear", yet his audible signal told him it was at "danger". This immediately causes him to doubt whether his audible-signal apparatus is working correctly, and, as doubt is one of the last states of mind a driver should be in, I think that the only place for such an apparatus as that mentioned should be at the signal itself, which fact would allow the driver plenty of time to get his train under control and be prepared to stop at the home signal. Mr. Snel

Mr. W. S. Roberts: I am quite in agreement with the author's remarks on page 766 that no hard-and-fast rule can be laid down in regard to distant signals, and that each installation should be decided on its merits. I also agree that in certain instances the provision of distant signals for each route has been overdone. I think, however, it would be as well to review the circumstances which have been responsible for the present practice as they appear to me. Some time ago the practice prevailed in certain directions of allowing a distant signal to be lowered in conjunction with home signals for several diverging routes. The disadvantage of this was many times made evident by mishap after mishap due to the driver thinking he was taking another route. This primarily led to the locking of the distant signal for the main road only, and the driver had to pass it at "danger" for any other routes. This was not satisfactory, as it did not tell the driver whether he was to be prepared to stop at the home signals or whether he was to be prepared to take another route, consequently he had to rely upon his judgment as to how the particular train was usually dealt with at the particular place. Such conditions not being satisfactory the practice grew, more or less, into providing a distant signal for each running-route home signal. This, as previously mentioned, was in many instances overdone, and without doubt contributed to the outcry against so many "red lights" being exhibited and so many lamps having to be maintained. Recently the tendency has been to encourage the cutting down of the number of distant signals, but if we revert to the practice of only single distant signals it is, in my opinion, a retrograde move and it would seem apparent that we shall have again to go through all the trouble which formerly encouraged Mr. Rob

[illegible]

and at the other end of the section the automatic operator [illegible] removed by [illegible] mention it. [illegible] which in turn would cause the brakes to be applied, and also for the driver at the end of the journey to account for the circumstances which caused him to lose this particular [illegible]

[illegible] p or trip valve to stand the [illegible] I do not [illegible]

[illegible] principle in the case of [illegible]

In [illegible]

represent the [illegible] At the [illegible] the [illegible]

Dr. Kapp. train is running on "line clear" the reed of the K.K. relay is swinging and makes contact in a local circuit which contains a continuous-current electromagnet holding its armature up. When the train enters into a section where the wire 1 is deviated into position 3, the reed of the relay ceases to swing and breaks the local circuit, causing the armature of the continuous-current magnet to drop; this movement is used to sound a whistle, and if the driver neglects to apply the brake within a reasonably short time, it is applied automatically. In any system of signalling there must be some transmission of energy. In the mechanical train-stop the transmission is by impact through levers, wires, and connecting rods; whilst in the railophone electromagnetic system the transmission is by etheric waves. Mechanical organs may break, but ether waves cannot break. There is thus no more reliable agent for the transmission of energy than the ether, and for this reason I consider an electromagnetic system to be a much more reliable link between the signalman and the driver than the most elaborate mechanical-impact system. In Fig. B is shown the arrangement for giving warning

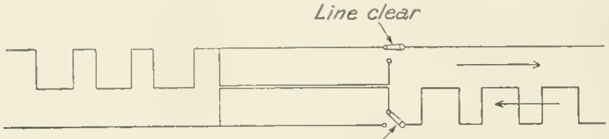


FIG. B.

signals, mentioned in the paper as in use on the Midland Railway. For simplicity I have shown deviation loops, though actually a slightly different system known as appendix loops has been installed. The effect is the same, but the amount of ground wire in the deviation loops is less; and this improvement lately introduced by Mr. Kramer is likely to become standard practice. The deviation loops are connected with the line wires by switches mechanically controlled by the same levers which operate the signal arms. It will be noticed that a bad contact in any of these switches gives the danger whistle, thus announcing itself. In front of the deviation loop proper are three short deviation loops which are permanently in circuit, thus giving three short whistles when the train is approaching the distant signal. The time is too short to allow of the brakes being applied automatically; the three whistles merely call the attention of the driver to the fact that he is approaching the distant signal. If it is at "line clear" nothing else happens and the train runs on. If it is at "danger" the whistle sounds on entering the section and the driver applies the brakes. Since the relay is of the resonating type it requires an extremely small power to keep the reed in vibration. The tuning need only be accurate to within 1 or 2 per cent, a condition easily filled with modern alternating-current machinery.

Mr. Strange. Mr. C. E. STRANGE: On page 772 the author refers to the reversible working on the London, Brighton & South Coast Railway approaching London Bridge terminus, and it seems to me that this system is one which possesses great advantages and lends itself to adoption on those sections of our railways which have to cope with a dense suburban "up" traffic in the morning and a "down" traffic in the evening. On pages 773, 774, and 775, the advantages gained by the introduction of track circuits are very well brought out. On page 774, towards the bottom of the first column, the author says that the act of changing running rails necessitates the breaking of rail bonds, which at once throws out of gear the protection given by such appliances. I think that the phrasing of this sentence might lead the uninitiated to draw an erroneous inference, and I take it that he means that the breaking of the circuit due to the changing of the running rails throws the apparatus out of gear and not the protection given by the apparatus, because the fact of changing the rails by breaking the continuity of the track circuit causes the signal to stand in the danger position and absolutely prevents it going to the clear position, thereby creating instead of doing away with protection. In other words, should a rail be removed, the track is in an unsafe condition for the passage of trains, and the fact of the removal of the rail, causing the signal to remain at danger, prevents trains passing over unsafe track. The author states on page 781 that a yellow light "can be seen farther than red or green, but does not show the colour distinctly until comparatively near to it; foggy atmosphere, moreover, tends to make the glasses appear quite reddish at times." When a third colour was found to be necessary, the yellow was chosen because it could not be confused with the green, or under any conditions taken for a clear indication. As the author says, under certain atmospheric conditions it may have a reddish tinge, but in practice this is never sufficiently marked for it to be confused with the red indication. One might say that such conditions cause the yellow light to appear to be of an orange colour. It should also be remembered that the yellow light never has to be distinguished at long distances, because the driver does not need to bring his train to a complete stop after sighting the signal and before he reaches it. The yellow signal is a warning and not a stop signal, and on account of its usual location only needs to be distinguished either just before or when passing it.

Dr. Garrard. Dr. C. C. GARRARD: This paper deals with a highly technical subject which can only be adequately discussed by experts who have specialized in it. From a general point of view, however, I think we may say that it is a very encouraging paper for electrical engineers, since the author's opinion is that the all-electric system of signalling on railways is the best. What impresses one on reading the paper is the marvellous development that has grown out of such a simple thing as a railway signal. I think we may take it, however, that the use of electricity enters into the domain of railway signalling as a simplifying agency, exactly as it does, for example, in the driving of workshop machinery. It is much simpler to lay out the power transmission of a workshop with the electric drive than it is with mechanical drive. In a similar manner it is simpler to lay out an all-electric scheme of signalling than any combination of other systems. In fact, it is clearly shown in the paper that many problems in signalling can only be solved by the use of electricity. In engineering generally, simplifying agencies are always to be welcomed. It is therefore from this point of view and as another example of the great assistance which electricity renders in other branches of engineering that this paper is of such great interest to the Institution.

[illegible] inter- [illegible] is the [illegible]

[illegible] when a [illegible] It will [illegible] owing to the distant signals being superseded. I do not consider it will be possible entirely to dispense with distant signals ; the difficulty which the author points out, so far [illegible] an upper-quadrant distant signal the proper distance out, [illegible] present system is that all signals in the horizontal [illegible] are "stop" signals.

Mr. A. E. TATTERSALL (*communicated*): The author's description of the interlocking block is interesting and is [illegible] but the electrical circuits are arranged to secure the same end. We also take the lock release through the signal arms themselves, so that in the event of a signal hanging [illegible] are now installing [illegible] with the lock and block. Such a course has much to recommend it and greatly improves the efficiency of the system. The author is to be complimented on the neat [illegible]

[illegible] to be gained [illegible] could not possibly be dealt with efficie[illegible] combined type is that facing points are alw[illegible] motorman or driver has also to descend from the train to re-set the trip lever, thus ensuring that a train has been [illegible] ground will be found for some time. I think that [illegible]

Mr. Tattersall. think the alternating-current system will eventually supplant the continuous-current system of track-circuiting in this country, especially for installations of magnitude. In addition to marking the latest phase of electrical operation, an alternating-current system possesses the following advantages in addition to those mentioned by the author :—(1) It affords an economical system of power transmission and the mains may be utilized for purposes other than signalling, such as lighting, power, etc. Varying pressures may be obtained with a minimum of loss, viz. transformer losses only, whereas with continuous-current transmission the watt losses due to inserted resistances may be considerable, and in some cases exceed the actual power required for signalling purposes. (2) Alternating-current track circuits will operate over a much greater length than continuous-current track circuits, as owing to the extra power available the question of track insulation does not enter into consideration to anything like the same extent as with continuous-current track circuits. (3) Extraneous currents, even from an alternating-current supply, may be fully guarded against, either by using suitable frequency relays, or by employing some form of apparatus embodying the principles of electrical resonance. There are several extensive installations of alternating-current track-circuiting in this country, notably on the Metropolitan Railway, East London Railway, Central London Railway, the extension of the Bakerloo Tube, and the London & North-Western Railway. I think the Metropolitan Railway was the first English company to obtain sanction to dispense with locking bars where track-locking was in operation. This was about four years ago, and locking bars are not now provided. I think the arrangement of semi-automatic signalling "B" is to be preferred owing to the control afforded the signalman in advance. As to the flexibility of semi-automatic signalling; on the Metropolitan Railway there are only three power interlockings, the remaining interlockings where track-circuiting is in operation being equipped with manual interlocking frames. I think there is a great field for track-circuiting in the case of single lines of railway. As increased traffic facilities are required, track-circuiting could be installed to provide several sections for following movements, whilst opposing movements would be fully safeguarded as at present. Upper-quadrant signals have been in use on the rapid-transit lines of the Metropolitan Railway for four years, and a few are also in use on the Central London Railway. I do not agree that the use of 3-position signals would tend to prevent close working, especially on the Underground Railways. I think the contrary would be the case, and that the author contradicts himself in the next paragraph. I do not consider the idea of 3-position signalling to be to dispense with distant signals, as in long sections distant signals would still be retained, but the "caution" position would be given by the arm inclined 45°, instead of horizontal as at present. The main idea of 3-position signalling is in my opinion to convey more information to a driver than is possible under the present system, and at the same time to simplify the signalling aspects. I think the author might overcome his objections to the yellow light by employing a red marker light as some of the American railroads do. It certainly would assist a driver in having something to help him in picking out the yellow light. One advantage of the constant detection system is that a visual indication is given to signalmen, showing the position of all points under their control. Not only is the constant detection system advantageous from a maintenance point of view, but it permits of far more elaboration in the detecting arrangements than is possible with other systems. Owing to the advantages enumerated by the author and those outlined above, I think constant detection will become standard practice in future power interlockings. The dynamic indication system fully safeguards the operation of the check lock and is a distinct advance on previous indication systems. It does not permit, however, of a constant indication being given. I believe that the McKenzie, Holland & Westinghouse Power Signal Company are now utilizing alternating current for indication purposes, which in addition to safeguarding the indication circuit permits a constant indication to be given. This will, I believe, provide the ultimate solution of the indication question.

Mr. Downes. Mr. F. DOWNES (*communicated*): The passing of "The Regulations of Railway Act" in 1889 speeded up the introduction of block and interlocking, and how well the contrivances then introduced have served the purpose is shown by the comparative immunity from accidents, further contributed to by the superior training and care of the railway staff, but there is again an indication of another transition period due greatly to the speeding-up of railway traffic, which has grown enormously since that date. So urgent has the necessity for a fuller carrying capacity of existing lines become, that already many innovations in signalling appliances are adopted, but there is too great a tendency to adhere to old rules and regulations, and in this way to limit materially the advantages to be gained. Apart from liability, under some circumstances, to create unnecessary delay in main-line working, automatic signalling provides for the elimination of signalmen's errors; but until a reliable train control, effective at all speeds and in all weather conditions, becomes practicable at reasonable cost, complete transition will not be attained, and doubtless the lack of unanimous agreement on the part of railway officials as to the particular type or method seriously hinders the development of this appliance. A device operated without mechanical or electrical contact on the permanent way appears most desirable owing to the risks of damage thereto being reduced to a minimum, and the results of the experiments made by the Midland Railway are awaited by many with keen interest. I agree with the author that it is not desirable to give visual indications in the engine cab, as not having been converted to the principle of abolishing the semaphore signals I consider that the driver's attention should not be diverted from the observation of these signals and the regulations pertaining thereto. Failing the solution of the problem without the use of contacts, I am of the opinion that an effective train-stop could be devised suitable for the present, or automatic form of signalling, if operated on the principle that the device carried on the locomotive, and intended to come into contact with suitable apparatus on the permanent way, shall be so designed that it shall be broken by impact and apply the brakes when the signal controlling the stop is at "danger". It is also practicable so to arrange the apparatus that if the driver had his train under control, by partial application of the brake, he could render the engine equipment inoperative; but the difficulty remains that a

[illegible] interruption in working due to extraneous currents and leakages. In outlying districts, however, there is not the same necessity for the application of alternating-current track-working, but in some provincial districts stray cur- [illegible] It would have been interesting if the author could have included in his paper a description of the working of alternating-current methods of track-circuiting in which the energy is converted from that generated by primary [illegible]

Mr. J. C. Sykes (*communicated*): With reference to the first paragraph under the heading "Lock and Block" on page 763, it is curious to reflect that in 1872, *i.e.* before the time referred to by the author, the inventor of the lock and block system (Mr. W. R. Sykes) really tried first to intro- [illegible] not quite clear that there is any essential difference between the cancelling arrangements used on the Midland Railway and those employed elsewhere; and with regard [illegible]

[illegible] defect, for the ramp R is struck by the [illegible] remarks that "any failure is on the [illegible] always acts in a positive manner to denote that the [illegible] shunt is effective. If the shunt is ineffective, what is there to act in a positive manner? On the [illegible]

[illegible] the author's [illegible] admitting the necessity of providing a distinctive indication on home and starting signals where track circuits are [illegible] bad weather such as fogs or snowstorms drivers would find [illegible] better arrangement [illegible] the line, and in [illegible] Railway, and are quite satisfied with [illegible]

[illegible] fixed on the [illegible] latter being fixed with [illegible]

Mr. Whysall

the flashlight would "kill" the steady light. I attended a demonstration of the flashlight some time ago, when it was shown that an ordinary steady light became very indistinct when a flash-light was fixed near it. I was very interested in the description of the locking frame used on the Midland Railway. I can quite appreciate the author's view in regard to the advantages that this type of frame has over the more usual type. It should certainly be easier to fix, and should facilitate alterations, but it would appear that owing to shorter leverage the signalman's work would be heavier, particularly where the facing-point lock bars and points are worked off one lever, as, for instance, on the Midland Railway. In connection with points, the author has referred to the use of cast iron for trestles and cranks, instead of wood. It will probably be of interest if I mention that concrete blocks have been used very successfully on the District Railway for this purpose; and I should imagine that concrete would compare very favourably with cast iron as regards first cost, maintenance, etc. I think the chief advantage that the upper-quadrant signal has over the usual lower-quadrant type is that the total weight of the arms can be considerably reduced, the counter-weight being unnecessary. It is possible to obtain the same gravity-return effect with an upper-quadrant arm of about half the total weight of the lower-quadrant type. This reduction of weight is important, as it reduces the momentum and consequent wear and tear. The "clear" signal is also certainly much more arrestive in the upper quadrant than in the lower. Yellow lights were adopted in place of red for repeater signals on the District Railway with a view to reducing the number of cases in which drivers had to pass red lights; for instance, repeater signals fixed about midway in station platforms, it being argued that if a man were allowed to pass a red light in some places he might do it in others with disastrous results. I admit that yellow is not an ideal signal colour, but we wanted a third and it was the best we could get. I may say that although the climatic conditions on the District Railway are not always ideal, there has not been one case where the use of a yellow light has introduced any difficulties. The author states that it is a debatable question whether a signalman can attend to many more roads under power systems than under manual systems. During the "rush hours" on the District Railway 98 trains per hour are passed through Earl's Court station. There are four roads through the station, a double junction on the west side, and traffic has to pass to three roads east of the station. All these trains are signalled by one signalman operating a power frame; I think a signalman doing the same thing with a manual frame would have a hard time and would become exhausted towards the end of his shift. In connection with the electro-pneumatic system the author states that the mechanism for operating points is placed outside the 4-ft. way. It might be of interest to describe the practice on the Tube Railways. Naturally the ground space outside the 4-ft. way is insufficient for fixing the point lay-out. When power signalling was first installed on the Tubes, all the gear with the exception of the facing point locks was fixed on to the side of the tube, being bolted to the segments and connected to the points by means of rods and bell cranks. This arrangement worked satisfactorily, but the wear due to the use of the bell cranks was very severe, and our latest practice has been to fix the whole of the apparatus with the exception of the electromagnetic valves in the 4-ft. way. The valves are fixed on the segments and connected to the operating air motor by ½-in. pipes. There is a conductor rail in the centre of the 4-ft. way, so that the space available for the point mechanism is very limited, and the apparatus has to be specially designed. It has worked so satisfactorily that the same lay-out has been adopted on the open sections of the Tube Railways in order to keep all lay-outs standard. The author has referred to the comparative merits of "constant-detection" and "check-lock-return-indication." Each system has advantages over the other, but I think a combination of the two is desirable. In both systems the apparatus is located in the signal cabin and wires run from the signal cabin to the points, with electrical contacts at the points. The contention that troubles can be located in the signal cabin applies equally to the check-lock system. Any fault on the wires running to the points or defect on the points naturally has to be looked for outside the cabin. The chief claim in favour of the constant-detection scheme is that it renders unnecessary the running of additional wires for taking the signal circuit through the points over which the signals read. This is necessary with the check-lock system to guard against points being thrown after the indication has been received. The benefit claimed for the constant-detection scheme due to the fact that the point lever can be pulled right over without waiting for the indication is problematical. I think it is advisable that a signalman should know immediately when a pair of points fails to throw; and it is a good plan to complete each movement before commencing on another one. This is achieved by the check-lock system—each movement being proved as it is made. In making a number of point movements in the constant-detection scheme it may be found that after several levers have been pulled one pair of points has failed to throw, and due to the inter-locking several levers would have to be replaced so as to operate the points that had failed a second time, much valuable time being lost. Further, in installations where the signals are selected over the point levers, and the signals are "disengaged" by track circuit, the signalman has to wait before he can pull the signal lever for the indication on the points, otherwise the signal will not come "off".

Mr. Lascelles.

Mr. T. S. Lascelles (*communicated*): It is very satisfactory to see the author's recognition of the value of lock and block in preventing accidents and to find that the system has been so extensively and successfully applied on his own railway. The method of working the "warning arrangement" by means of additional block instruments has been adopted, in conjunction with Sykes' system, on the London, Brighton & South Coast Railway at many points and has been found vastly superior to the hand-flag and verbal warning used in the ordinary way. It would be interesting to know if the author has any such arrangement in use in conjunction with the rotary block instrument. I am inclined to think that track-circuiting would prove a much more satisfactory means of releasing the block instrument than a treadle—even of the "last vehicle type." This last has to be in the nature of a fouling bar and is a large affair, while with a stick relay and lever switch it is possible to get the last-vehicle clearance very simply. No treadles are then required.

[illegible]

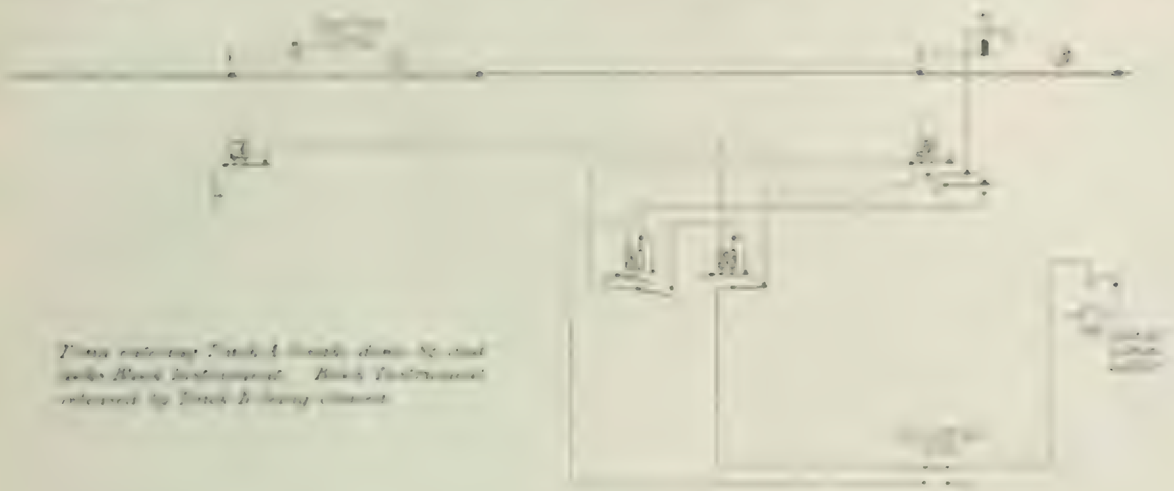


Fig. C.

[illegible] type with "last vehicle" features, and the track circuit for effecting the release can be placed where desired. When a train enters the preliminary section it breaks down the [illegible] this the train must pass through the second track circuit [illegible] put back to normal before the release of the instrument is effected. With regard to the universal pattern of signal arm, the choice would seem to lie between the ordinary one now used and the "somersault" type in use on the Great Northern Railway. It would be interesting to know the author's opinion of this pattern of [illegible] power is plentiful an indicator might be constructed on the [illegible]

[illegible] I believe that on the Midland Railway the code is a very complicated one, the "call attention" signal having to be given even before the "train entering section" signal, and in addition to all the ringing, needle signals being also [illegible] seemed to me that if each box or division of line were [illegible] be modified here and there to give the greatest opportunity for speed and simplicity. For example, at [illegible] tion-boxes it would be possible to abolish the unnecessary [illegible]

Mr. Lascelles.

the form of train describers would furnish the necessary information of this class, and so the large number of bell signals to describe the various classes of trains could be abolished. In connection with automatic signalling I should like to ask the author whether on the Midland Railway the signals are placed to "danger" directly they are passed, or not until the overlap is passed by the first wheel. There is a loophole for an accident with the latter method, which is shown in Fig. D. Imagine a disabled

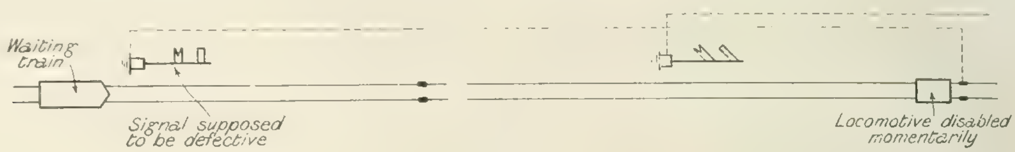
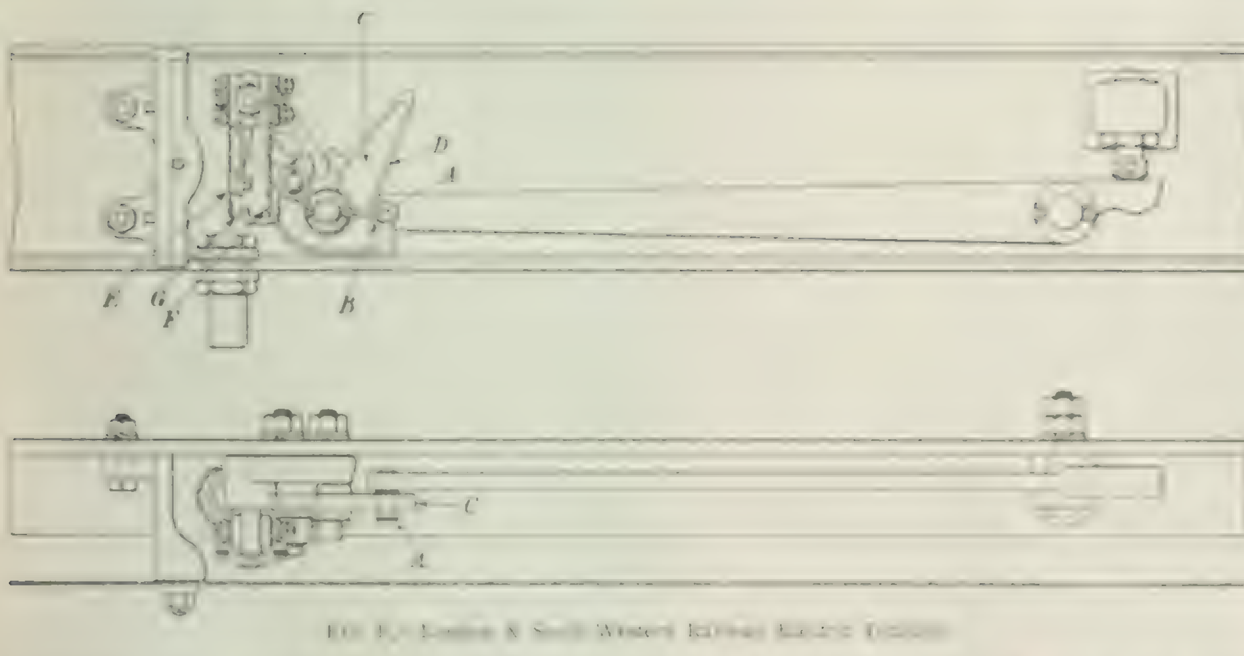


Fig. D.

engine to be stopped momentarily just before the end of the overlap—or somewhere in the overlap—and the weather to be foggy. The following train finds a signal against it and waits the prescribed time interval and then proceeds. On sighting the next signal it finds this at "proceed", and concluding the first one has failed, at once speeds up and comes into collision most unexpectedly with the disabled engine. The overlap section should preferably be a separate track circuit and should place the signal to "danger" immediately it is entered. The author has pointed out the mistakes that enthusiasts for power-signalling schemes fall into, of supposing that men can be reduced to a negligible quantity and the speed of working vastly increased. The electro-mechanical system now being extensively adopted in the United States enables many of the advantages of power working to be obtained without the troubles of maintenance and operation that are liable to attach to power-worked points. These are the most expensive and delicate parts of a power system, particularly in an all-electric system. By far the largest part of a locking frame usually consists of the signal levers, and by exchanging that part of the work for an electric frame considerable space can be saved while the comparatively simple method of manual working for the points can still be retained. Reduction of effort on the signalman's part can be obtained through the balancing of levers (as I believe is the Midland standard practice) and the adoption of switch and lock movements.

Mr. Thorrowgood.

Mr. W. J. Thorrowgood (*communicated*): I think the word "absolute" in connection with block is no misnomer, but a reality. Obviously, if the block system were carried out by all concerned, there could be no collisions. The human element is not perfect, but the failure to maintain absolute safety cannot entirely be debited to signalmen and drivers. At places it is found that the exigencies of the traffic are such that the number of lines of railway is insufficient to allow of absolute block working. Then a modification of the absolute is asked for under permissive block working, with safe conditions no doubt, but not absolute safety. The reason for this is of course that the expense of increasing the number of lines would be excessive. That may be so, but still it remains that safety has been compromised with. The fact is not generally recognized that it is well-nigh impossible to get anything that is absolutely everything one requires. We want absolute safety, but then at the same time we want to use the lines to their maximum capacity; the result is that one comes to a compromise by getting as much of both as he can. The lock and block system requires no justification to-day, for the freedom from accidents, even when considering those due to the misuse of the key, is generally conceded to be much greater where it is in use than where block alone is used. Here again we have an absolute system, but as the author shows in the last paragraph on page 763 "there are certain limitations to its adoption, as sufficient elasticity cannot be obtained;" that means the capacity of the lines is insufficient to allow of absolute lock and block working and a compromise is made, which is safe as long as the human element conforms to the rules. The necessity for the key arises through the complications of the traffic. It has to be borne in mind that block-working is for through or station to station working, whilst locking is for local or station work. Often the conditions of the two as regards traffic do not agree. In cases of faults trains would be liable to severe delays unless a key were available. It is really a compromise between an absolute system and traffic conditions. Everything possible should be done to guard the use of the key. There is no system of signalling in use that does away absolutely with the key or a release in some form or another; the human element has then to be trusted. The use of track circuits instead of treadles in combination with lock and block is a real step in advance. We found that mercury, although "pure redistilled," gave trouble, and two pattern treadles of the spring-contact type have been introduced on the London & South-Western Railway. Fig. E illustrates the Syx spring-contact treadle. The end A of the lever is raised by the action of the train passing over the rail on which the treadle is fixed, and in passing over the semicircular insulation B forces spring C backwards into contact with D on spring E; both springs are forced a little further back, causing a rubbing contact. Normally the end of lever A rests near the bottom of treadle, and is free to move a short distance before commencing to engage with B. Fig. F illustrates the McKenzie and Holland rocker spring-contact treadle. Normally the end of the lever A rests in a recess B at the lower part of the rocker C. As the train passes over the rail, the end of the lever A is raised out of the recess B and travels up the face D of the rocker, which causes springs E and F to make contact at G. It can be arranged that the contact is made directly the end of the lever leaves the recess and arrives on the face D. Thus it can be made very sensitive, but it is found in practice that it is better if the contact is made when the end of the lever is about one-third up the face of D. The end of lever A, as it returns to normal, after it has been operated, falls into the recess B, thus ensuring that the rocker shall return to the normal position and



the strength that can be

Mr Thorrowgood.

plate bolts from the rails. Hence the mechanical strength and fit of this class of insulated fish-plate are more than equal that of the ordinary fish-plate. Very little trouble is experienced with the transverse bolts, the percentage of breakages being much less than with ordinary fish-plates. I think it would be interesting to refer to a new pattern of insulated fish-plate called the rolled-section type of insulated fish-plate, which was under experimental and practical test for about two years on the above railway, and has lately been introduced on that and other railways. Fig. G illustrates the new insulated fish-plate and the method of fixing to the rails. The insulated fish-plate is made from rolled-section steel, each plate consisting of three pieces of rolled

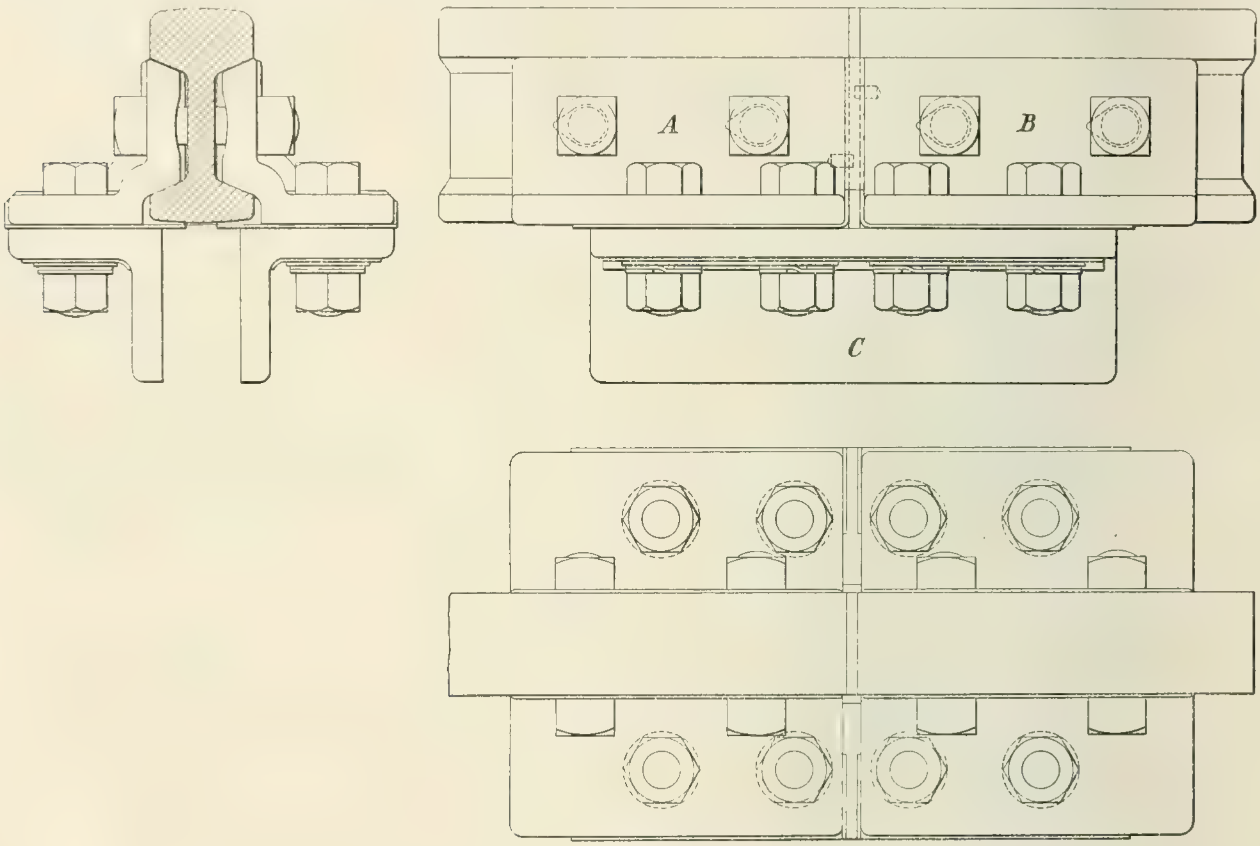


Fig. G.

section—A, B, and C. The faces of A and B, which are to be fitted to the rail, are planed to fit the rail in the same way as an ordinary fish-plate does. A and B are bolted to C as shown in the diagram. Thin sheets of hard insulating fibre are used to insulate A and B from C. The ends of these sheets are turned upwards and a thick piece of hard insulating fibre serves to insulate A from B. Bending tests show that this rolled-section insulated fish-plate is stronger than the transverse type, and it has the merit of being less costly. The mechanical strength and fit are therefore all that is required. A point to be noticed is that when insulated fish-plates of this pattern are used, the cost of the ordinary fish-plate is saved, and the cost of fixing to the rail is the same as that of an ordinary fish-plate, as no other fitting is required. The advantages of track circuits are obvious, and no doubt extensive use will be made of them in future. The weak spot as regards the use of track circuits to-day is the fact that there are a number of vehicles fitted with Mansell wheels (*i.e.* wooden blocks) belonging to various companies running over the railways. The resistance between the rim of one wheel and the rim of the other wheel of a pair is practically infinite as regards the track circuit, hence they fail to shunt the current from the relay and thus fail to operate the track-circuit apparatus. The difficulty can be overcome if the hub of the wheel is bonded to the rim on each wheel. A very large number of wheels have been treated thus; but it cannot be too strongly impressed on all concerned that the wheels of such vehicles in service should be bonded. It is an urgent necessity, as such a vehicle standing on a track-circuited section does not operate the track circuit, therefore a clear signal is given to the signalman whilst the road is blocked. The use of sand by drivers should be discouraged as much as possible, as the accumulation of sand on the rail is likely to set up resistance between the rail and the rim of the wheel and thus cause even a heavy engine to fail to operate the track circuit. Fortunately this difficulty is generally local—immediatety behind signals where trains stop and start—and has been met in several places by means of electric fouling bars in addition to the track circuits, the contacts on the electric fouling bars being joined in series with those of the track-circuit relays in the secondary circuit.

[illegible] may run back on to a track circuit locking signals in the [illegible]

Mr. W. C. A[illegible] (in reply, [illegible]): Mr. [illegible] [illegible] one of the many difficulties that have to be overcome in making the signalling suit the lay-out of the roads.

[illegible] would very seriously delay the working of the traffic. In regard to the position of the relay in track circuits, it was originally the general opinion that it should be fixed at the entering end (from a traffic-running point of view) of the track circuit, but in present-day practice it is not considered a matter of any importance. The track circuit outside the outer home signals (Fig. 14) could be con[illegible] arrangement shown defines the position of an engine or short train more correctly to the signalman; but if a track is provided outside the inner home signal it should [illegible] between the inner and outer home signals being protected [illegible] block instrument in the "train on line" position. Fig. 20 is not intended to illustrate a 3-position signal installation; the signals for one direction are to illustrate arms working in the lower quadrant, and those in the other direction in the upper quadrant. The 3-position signal will undoubt-[illegible]

[illegible] affected.

In reply to Dr. Kapp's remarks in regard to the experi-[illegible] diffi[illegible] therefore would be difficult to keep [illegible] than 900 to 1,000 yards from the s[illegible] on the train. Such a [illegible] be very interesting to t[illegible]ng world generally.

[illegible] changing running rails, so far as automatic s[illegible] the signalman, without [illegible] locks, it is very desirable [illegible] although a train may be occupying a line the indication [illegible]

[illegible] The d[illegible] suffice.

[illegible] block, the rear starting lever is released by turning the [illegible]

Mr. Acfield. for each "line clear" indication given. Mr. Tattersall's remarks on the 3-position signal and retaining distant signals in long sections would point to the fact that the distant would after all only be a 2-position signal, the normal position of the arm being inclined to 45° instead of horizontal. In the cases on the Underground Railways referred to, I have been given to understand that a 3-position signal would not give the facilities of special working mentioned in the paper. I hold no serious objections to yellow lights, but suggest that it would be a pity to increase the number of lights on a railway by the red marker lights mentioned.

Mr. Downes' communication dealing with the point of application of train-stops raises a very interesting question, and one that will have to be faced when a satisfactory apparatus can be produced. Doubtless, the distant signal is the point at which a train should be tripped, but even then, difficulties will be met when it is necessary to deal with signals normally fixed at danger. I do not quite follow the suggestion of providing automatic sections between long sections of 3-position signals, as the latter are necessarily automatic signals.

Mr. Sykes refers to the continual renewal of the fibre of the insulated joints at more or less frequent intervals, but this does not apply to the Midland pattern of insulated rail joint, and Mr. Tattersall's remarks clearly show the popularity of this device, now used to a large extent on English railways.

Mr. Openshaw does not appear to approve of white enamelled signs, but prefers indicator lamps. This matter has received very careful consideration, but these signs are thought to meet the case, as they are looked upon as a reminder to drivers of exemptions from Rule 55 (lists of such exemptions are published in the traffic notices), and the signs are more economical than lamps.

Mr. Whysall refers to my remarks on a signalman with a power system being able to attend to many more roads than under manual systems, and as an instance quotes busy places where regular services of trains travel in similar directions, whereas my remarks refer more particularly to terminal or other stations where much shunting and making-up of trains is accomplished.

In reply to Mr. Lascelles, the rotary interlocking block, as designed and used on the Midland Railway, is such that traffic can be worked under the "warning" arrangement Mr. Acfield or any other regulation of block working generally in force, and thus affords the necessary elasticity for passenger and goods traffic. The Midland pattern of insulated rail joint, of which there are several thousands in use, has proved itself to be substantial and effectively satisfactory in every way. I agree that track circuit in lieu of treadles or bars for releasing the block instruments should prove more satisfactory and give greater protection. This problem has already received serious consideration by the Midland Railway, and a scheme for doing this has already been formulated. With regard to the alleged complications of the Midland code of block working compared with those of other companies, I suggest that the great variety of traffic must of necessity involve a larger number of calls, but these are reduced as much as possible by utilizing the block instruments for "describing" and "routing" purposes.

In the semi-automatic signals installed on the Midland Railway the arms are in some cases placed to "danger" when the 440 yards overlap is cleared, and in others directly the signal is passed; but the engine driver is not allowed to proceed after being stopped at a signal until he has telephoned to the signal-box and received permission to proceed.

Mr. Thorrowgood appears to question the efficiency of the Midland pattern of insulated joint, but the imaginary troubles suggested are not experienced, and the joint has superiority over other joints as it can be used in confined positions. It would appear that the rolled steel section of insulated fish-plate could not be used for insulating a check rail, which frequently becomes necessary in large track-circuit installations.

Mr. Cooke raises the question of breaking up trains outside the home signal for attaching or detaching vehicles. The track circuit outside the home signal is a good scheme and can be used in combination with a treadle, or preferably with another track circuit inside the home signal. In traffic working, other than ordinary suburban working, there are a great number of problems that the Midland Railway have satisfactorily provided for in the large number of installations that have been put in for the protection of trains detained at home and starting signals, with all classes of traffic, to exempt drivers from carrying out Rule 55.

A PLEA FOR SCIENTIFIC AND TECHNICAL COMMISSIONERS.

By W. Pollard Digby, [illegible] Associate Member.

[illegible]

loom. Possibly it will involve both.

(4) [illegible] States, will not be imposing such heavy burdens of [illegible]

(5) [illegible] thereby rendering it the more necessary that American manufacturers should hold their own in neutral markets.

[illegible] the intelligence service of a field army, and the better the [illegible] sooner will be the recovery from the aftermath of the war. [illegible] should be complete in itself through the exactitude of its [illegible] not for a [illegible] that this is the only point to which thought should be given. He does [illegible]

[illegible] Commissioners. [illegible] to describe [illegible]

[illegible]

[illegible] Protectorates there are various correspondents designated [illegible] Colony, [illegible]

The reports published are mainly [illegible]

syndicalization on internal and external trade. In the latter Mr. Wickes has rendered good service to the electrical manufacturing industry here by his reports on the influence of fire-insurance requirements in North America on the types and necessary tests of the fittings to be used.

From the foregoing recital it will be realized that there is much information from these and other sources which our manufacturers ought to have, and which the reports cited, admirable though they are in their way, do not give. Why they are not and cannot be provided, with the existing machinery, the present author hopes to make clear.

Unless written by specialists, neither the reports of Commercial Attachés and Trade Commissioners, nor the Consular reports, can be reasonably expected to give details, say, of the successful types of competing foreign manufactures, the reasons of lower price, the reasons apart from price why British types are not successful, and the local conditions which may render typical British articles unsuitable. Such reports can only be adequately written by specially selected men situated in friendly countries, having behind them all the prestige of our diplomatic service. The men to be chosen for the duties must be of a high type. They must be recruited with as much care as the secretaries of our various embassies and legations, but recruited differently. Education at a public school followed by a degree at Oxford or Cambridge, together with the possession of independent means, must not be the sole credentials—for really suitable men one or all of these may be dispensed with. Let us consider for a moment our Naval and Military Attachés. They are not selected as the result of brilliant University achievements following upon Eton or Harrow. Even the possession of Certificate B in the Officers' Training Corps would not be regarded by the Secretary of State for War as sufficient credential to qualify the most brilliant of the younger sons of an ancient and honourable house for the post, say, of Military Attaché at Petrograd. Even in the past, those who perpetrated the cheapest cynicisms at the expense of the War Office never charged it with regarding only the advantages of birth and education without regard to linguistic attainment and sufficient military experience, both regimental and staff college, when such posts require filling. The modern side of a public school, and an engineering degree at Cambridge, Oxford, London, or Manchester, are by themselves wholly inadequate credentials for a technical commissionership. Of great value as a foundation, all these are only a foundation, and not the only possible foundation. Industrial experience is as essential as the intervening years of sea service between leaving Osborne and a naval attachéship for officers in the Navy.

The Technical Commissioner should be a specialist. The Admirable Crichton is not available, and even if he were, he could not be ubiquitous. Let us imagine that some super-engineer has been appointed at some not too distant date. It is not so easy to imagine one so versatile as to be able to send useful reports on, say, textile machinery, metallurgical developments and processes, aniline dyes, extra-high-tension insulators, railway rolling stock, and large internal-combustion engines. Assuming, though, his existence, with all this varied and with even more encyclopædic knowledge, his further possession of the necessary gifts of tact, capability of literary expression, and grace of manner, he could, either as a consultant in Westminster or as one of the leading officials of a big firm, command an income comparable with that of a Major-General.

Specialists acquainted with the needs of distinct industries must naturally possess an all-round knowledge of those branches of applied science most closely related to their own special work. It has been said that the best specialist is an all-round man. To this definition we must add that the all-round man should possess imagination. Much, very much more than is supposed, of German success in the past has been due to the possession of a scientific and commercial imagination. Others, time and again, have done the pioneer work, have opened new fields of discovery, but it has been left to the imaginative Teuton to carry the discovery to its logical conclusion, to foresee its fields of application, and to build thereon great and remunerative industries. If we look back on the history of the evolution of any branch of science, or even of any piece of machinery, it is at once evident that at any stage the next advance might have been predicted by the intelligent putting-together of the then ascertained achievements and phenomena. To-day those concerned in many industries are marking time, unable to surmount present obstacles until the flank of the position has been turned by discoveries in another branch of science permitting the bridging of the gap before them. There must, therefore, be among the essential credentials of the technical commissioners evidence not only of practical experience and the power of succinct description, but of a logical imagination.

Before suggesting some typical cases with which technical commissioners could deal, we may consider briefly how technical information is obtained by firms in the United Kingdom and in other countries. First and foremost in value are specific visits of individual engineers abroad. These are directed mainly, if not entirely, to purchasing countries, not to competing manufacturing countries. Their visits are sporadic. Presumably they are sometimes sufficiently promising to lead to the firm in question opening a branch in the country or branches in certain of the countries visited. Some information comes from the technical Press, but there is of course an art in giving information to the technical Press closely akin to the sister art of concocting the generalities of some manufacturers' specifications for the plant they propose to sell. Then, too, there are occasional Institutional visits to competing manufacturing foreign countries, none utterly vain, but with the technical side obscured by much hospitality. Good though all these are, they are not adequate. The author has yet to learn of any British firm maintaining an intelligence department in any foreign manufacturing city, concerned in no way with the sale of the firm's products but with the sole duty of forwarding technical information—collected in various manners which need not be specified—to the firm's headquarters.

In place of this espionage, officially recognized commissioners could be of great value. It is unnecessary to discuss at length whether the proposed commissioners should be attached to the Foreign Office or to the Board of Trade, and if under the former whether in the diplomatic or the consular branches. There is the greater prestige of the diplomatic service which already has its commercial attachés, whereas even in the higher ranks of the consular service His Majesty's representatives have, to

[illegible]

[illegible] tions could submit names to the Secretary of State who [illegible] with those concerned in his work.

The technical commissioners should rank after, but be [illegible] shape of secret and confidential publications, will of course [illegible]

During a technical commissioner's hours of service, the [illegible] engineering commissioner for any particular branch of the [illegible] operation, and send home recommendations thereon. He would join the engineering Institutions of the country in [illegible] gresses or conventions, and abstracting promptly im- [illegible]

[illegible] The gigantic and superbly [illegible]

[illegible] activity as the duties of the Development C[illegible]

DISCUSSION ON

"THE BOMBAY HYDRO-ELECTRIC SCHEME."*

MANCHESTER LOCAL SECTION, 27 APRIL, 1915.

Mr. Peck. Mr. J. S. PECK: The paper deals with one of the largest power undertakings in the world, and the technical descriptions are of great interest, but there is nothing in the paper regarding the operation of the plant or of what successes or difficulties have been encountered. The regulation of the generators—22 per cent at 0·8 power factor—seems rather close, especially in view of the fact that automatic regulators are used. If the regulation were increased to, say, about 30 per cent, a cheaper and perhaps better machine could be obtained. It is stated that the voltage is automatically maintained by means of a Tirrill or Brown-Boveri regulator. Does that mean that both types of regulators are installed? If so, why? It would be interesting if the author could give a little more information and a few more details as to the actual mechanical construction of the generators. I notice that the bearings are water-cooled. Does that mean that the oil is cooled in a separate cooler, or is water passed through the bearing pedestal? I notice also that the water for cooling is taken from the main pipe line. I believe Mr. Moore said that 2 gallons of water per minute was equivalent to 1 horse-power. The water taken from the main penstock would have a considerable horse-power value, and I should think it would be cheaper to put in a small pump to circulate the water at a low pressure than to take it from the penstocks. The transformers, I note, are connected delta to delta. The usual practice now is to connect delta to star, and I think it is possible to obtain a rather safer transformer with this construction. Also with that arrangement it is possible to earth the neutral points in case it should be desired to do so. Is there any particular reason for using a delta to delta connection in this case?

Mr. Pearce. Mr. S. L. PEARCE: The author has given us a most interesting paper, full of valuable details descriptive of one of the largest hydro-electric schemes which have ever been carried out in any part of the world. The paper is essentially descriptive, and it is not so easy therefore to discuss it. One point is very striking, viz. that the whole of the water furnishing the power is collected from the rainfall during the monsoon season. Those who have been in India know that whilst the monsoon season comes round with precise regularity the amount of the rainfall varies considerably from year to year. Impressive as the figures are which have been quoted with regard to the size of the dams and the amount of stored water, it would seem possible that, owing to an exceptionally dry season, there might be a shortage, seeing that the whole of the power is derived from the monsoon water alone. It is a point I shall be glad to have further information upon. Then I venture to think that the paper would have gained in value if we could have had some idea of the cost of the installation. I do not mean so much the question of the transmission lines as of the power station and the hydraulic works. I remember a remark that was made to me some Mr. Pearce years ago by a Canadian engineer who was over in this country. The discussion turned upon the cost of some of the large water-power companies in Canada and the States, and he said this, "People in England seem to think that power will cost next to nothing if it is derived through the agency of a hydro-electric company, but in my opinion Britishers have got us absolutely skinned to death with the low capital costs incidental to their big steam-turbine power stations." That was a very striking remark. It goes to illustrate the point of view that these large hydro-electric schemes cannot always compete with the big steam-turbine power stations in this country as regards supplying power cheaply. It would be interesting to know why the unearthed-neutral system has been adopted in this installation. With regard to the arrangement of the main switchgear at the power station there is just one point I should like to bring out. That is in connection with the use of the transfer busbar. I admit that it is probably more usually adopted to-day, but it seems to me that the transfer busbar can be dispensed with by treating the step-up transformers and the generator as one integral unit. I think a scheme which eliminated that transfer busbar would certainly be cheaper; it is most assuredly less complicated, and I think on the whole it would be more reliable. This view has been expressed here before to-night, and I think it is on those lines in the future that probably the development of large high-tension switchgear schemes will be proceeded with. There is a point that I should like to make with regard to the cost of the supply to the mills. It seems curious that whilst energy is sold at 0·5 anna where the mills provide their own motor equipment, the additional price that is asked in the case of the company supplying the equipment is only 0·05d. I will assume that the standard rupee is equivalent to 16 annas or 16d., in which case one anna would equal one penny. It amounts then to this, that for 0·05d. on every unit sold the company have to pay the capital charges on the mill equipment. In this country with a mill of about 1,800 horse-power and a consumption of, say, $2\frac{3}{4}$ million units, the additional 0·05d. would bring in an additional revenue of £570 a year. Take a round figure of £7,600–£8,000 for the cost of the electrical equipment in a mill of the size I have mentioned. I notice that these agreements are for 10 years, from which I assume that a company conducted upon prudent lines would undertake to write down the capital cost within that period. On the basis of a 3 per cent sinking fund the company ought to allow $8\frac{3}{4}$ per cent upon the capital outlay in order to write down the cost within the said 10 years. If my calculation is right, that figure of 0·05d. per unit is little more than half what it should be if the cost of the mill equipment is to be written down within the period of the agreement. Can Mr. Moore tell us whether the company write down the equipment within 10 years or

* Paper by Mr. Alfred Dickinson (see p. 693).

[illegible] near the coast, but even there the variation from year to [illegible] event happened, the trade of the cotton mills—who form [illegible] that the demand for current would greatly fall. There [illegible] the commencement and it hung fire for several years. European capital was not attracted as the scheme was considered too risky. The fact that the water supply [illegible] evaporation and the faulty nature of the strata, and the [illegible] be expected to form the consumers, all these reasons combined and operated strongly against any chance of raising capital in this country. However, the Indian gentlemen [illegible] amount of power would have made good consumers with their big steady 12-hour loads, but they were already fully equipped with steam plant, much of it of a modern and [illegible] capital for electrical installations. The supply company, [illegible] manner. It offered to supply the whole of the electrical installation required in each mill free, provided the mills entered into a 10 years' agreement to take current at 0·55 anna (0·55d.) per unit. This enterprise had the desired effect, and I think that before the power station was built almost the whole output was contracted for.

[illegible] district; [illegible]

[illegible] made for evaporation during the [illegible] rain is collected. In some [illegible] morning in a very hot summer it went down 4 [illegible] provided for.

Mr C. C. Atchison: The [illegible] understand that in some cases an attempt has been made [illegible] case.

Mr. Crews. Mr. H. C. CREWS: Looking at the views shown upon the screen I was much impressed by the tremendous expense of a scheme like this, but can such expense be justified? I should like to ask what proportion of the 0·5 anna charged for current represents what we understand in this country as capital charges.

Mr. Allcock. Mr. H. ALLCOCK: This paper and Mr. Rider's recent paper serve to demonstrate the fact that the future of the British electrical engineer lies quite as much abroad as at home. The students and young engineers of to-day should therefore not hesitate to take advantage of opportunities of advancing their knowledge and understanding of engineering problems by taking up at once these positions. I should be obliged if the author could tell me whether the ends of the cambric-insulated cables are sealed in any way, and if not, whether any difficulty has been occasioned by their absorption of atmospheric moisture. I should also be very interested if he would give some comparative figures of the conductivity and mechanical strength respectively of the twisted sleeve mechanical joint, as compared with an equal length of unbroken conductor. We know these twisted mechanical sleeve joints have been employed fairly largely, and presumably successfully, especially in America on aluminium transmission lines, but they do not appear to have been used very extensively on hard-drawn copper aerial lines.

Mr. Fennell. Mr. W. FENNELL: It has occurred to me in the course of the discussion that a point arises with regard to the charges for the electricity supply from an installation of this kind. Most of the cost must be in the nature of standing charges and bears almost no relation to the number of units sold. Now in Bombay, just as in Manchester, there may come periods of bad trade when the financial basis of a concern charging a flat rate would be seriously jeopardized. I wonder whether the promoters of the scheme have considered the question of charging on the Hopkinson basis, *i.e.* a fixed amount per horse-power, to cover the standing charges, plus a small charge per unit to cover the running expenses, thus making the basis of charge follow the same law as that of the costs. I wish to point out that those responsible for the flat rate on a unit basis in the Bombay power scheme have departed from the established practice, which is to charge a fixed price per annum per horse-power derived from water power; and an explanation of the reasons for this departure would be of great interest.

Mr. Moore. [Mr. E. F. W. MOORE replied briefly on behalf of the author who was unable to be present.]

Mr. Dickinson. Mr. ALFRED DICKINSON (*in reply, communicated*): In reply to Mr. Peck, I would say that Tirrill and Brown-Boveri regulators were installed side by side, one as a stand-by to the other. A stand-by having to be provided, in this way experience will be obtained in the operation of both types of regulator. The generators are quite standard and of usual construction. The oil in the bearings is cooled by water passed through coils in the bearing pedestal. The service cooling water was taken from the main pipe line in preference to the operation of motor pumps. In a close comparison of all the factors in both schemes the method adopted was justified. Delta-delta connections were deliberately adopted. The matter is more fully explained in my reply to Mr. Rider in the discussion in London (page 720).

The answer to the point raised by Mr. Pearce in connection with the adoption of an unearthed neutral will be found in the reply mentioned above.

The observations of the Canadian engineer to Mr. Pearce as to certain hydro-electric schemes being unable to compete with large steam turbine power stations are no doubt true. All these schemes have to be judged upon their merits, and they are largely controlled by local circumstances. For instance, take the two cases of Johannesburg and Bombay. A large steam station in Johannesburg is more or less justified by the low price of good coal. The price of good coal there is roughly one-fifth of that of poor coal in Bombay. In my verbal reply at the meeting in London I stated my impression to be that in no country except India would the construction of such large dams be a commercial possibility—certainly not in Canada where the price of masonry per cubic yard would be at least three times as great as in India. I am certain that no steam station in Bombay could compete with the hydro-electric supply as installed.

In reply to Dr. Bowman, ample provision has been made for evaporation. No general rule can be laid down for evaporation, since so many points, each varying with the particular lake or district, have to be taken into account, such as the depth of water in the lakes, night condensation, the nature of the lake surroundings, whether of intense vegetation or bare rock, and so on. Mr. Joyner's judgment in this matter has been borne out in actual practice. I believe that there is no other instance on record where the evaporation approaches in extent that mentioned by Dr. Bowman.

The point mentioned by Mr. Atchison with regard to the governing of the turbines is dealt with in the observations of Mr. Doelly in the London discussion.

Mr. Crews' question was answered in my reply to the above discussion.

In reply to Mr. Allcock, I would say that the cambric-insulated cables are not specially sealed. Similar cables are in use at the Cauvery Falls installation, and in other parts of the world. So far I have not heard of any difficulty due to the absorption of atmospheric moisture. The mechanical tests made on the twisted joint showed that the joint was stronger than the conductor. No elaborate tests have been made of the relative conductivity, but I am satisfied that the adoption of this joint has in no way affected the efficiency of the line.

In reply to Mr. Fennell I have to say that practically all the known methods of charging for energy were considered, including those mentioned by him, which have their advantages and disadvantages. The method adopted is void of ambiguity and is satisfactory to the consumers. A fixed charge per horse-power per annum can only be justified where there is a continuous and abundant supply of water and where small capital expenditure is needed on development. The whole of the water for the Bombay project is stored water, secured at a considerable cost. A charge per horse-power per annum, in this case, would have to be abnormally high and therefore not so satisfactory to the consumer as the tariff adopted of payment per unit.

DISCUSSION ON

"POLYPHASE COMMUTATOR MACHINES AND THEIR APPLICATION."*

[illegible]

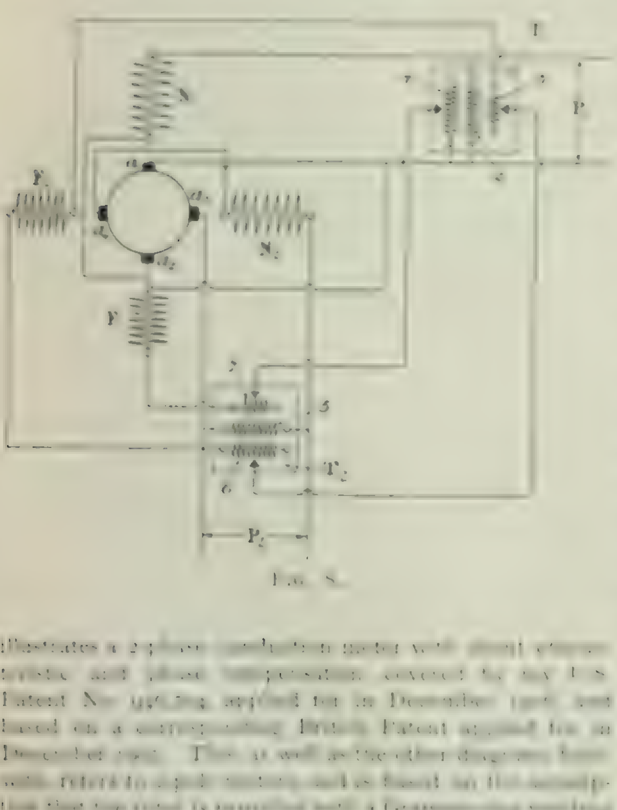


FIG. 8.

[illegible] and that the brushes rest directly on the said winding, thus eliminating all questions as to connections between the [illegible] the winding. The rotor is also [illegible]

[illegible] torque field, [illegible] to the brush a_1, the circuit being completed [illegible] The armature ampere-t[illegible] the transformer T_1, the primary 2 of which is connected [illegible] The working armature circuit of the second phase comprises brush a_2, the rotor winding along the [illegible] ampere-turns due to this second phase also co-operate with the motor flux due to the exciting winding F_2 to produce [illegible] the value of the compensating electromotive force [illegible] pressed on each exciting winding and derived from the [illegible] windings, while six are needed in the case of a 3-phase machine. In 1908, I conceived the idea [illegible] F_1 and F_2 of Fig. 8. I [illegible] use, then the rotor carries [illegible]

Mr. Fynn. heavier load falls on the revolving part of the machine, but this disadvantage is in part offset by a certain advantage, to which I shall refer presently. Which of the two possible combinations is to be preferred, entirely depends on circumstances.

Fig. T shows that form of the improved motor in which the rotor is put to a double use, in other words, the connections are so made as to cause the rotor to carry working as well as exciting current. But whenever the exciting winding of an alternating-current motor is placed on the rotor, the machine becomes self-compensating. This is the advantage above referred to and the point which I think the author has overlooked. This self-compensating feature is due to certain speed electromotive forces which appear at the brushes and so change the phase of the resultant electromotive forces impressed on the exciting circuits of the machine as to improve the power factor of the motor. The self-compensating speed electromotive force appearing at the brushes b_3 b_4 is due to rotation of the rotor conductors in the armature leakage field along the axis b_1 b_2. The self-compensating electromotive force appearing at the brushes b_1 b_2 is due to rotation of the armature conductors in the armature leakage field along the axis b_3 b_4. Being dependent on the armature leakage flux, these self-compensating electromotive forces of course vary proportionately with the load. At synchronism the pressure-drop due to armature reaction is entirely compensated in each axis by the speed electromotive forces referred to. Above synchronism the pressure-drop due to stator reaction can also be compensated. Below synchronism the pressure-drop due to armature reaction is under-compensated. These compensating speed electromotive forces naturally cause the machine to run at a more constant speed than would otherwise be the case.

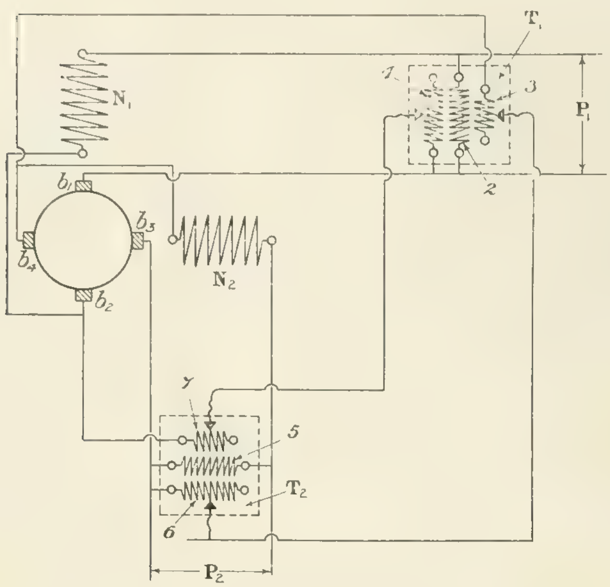


Fig. T.

In further explanation of the machine shown in Fig. T, I have prepared Figs. U and V. In Fig. U, phase P_1 is impressed on the armature circuit b_1 b_2 and N_1. The armature ampere-turns in this circuit co-operate, to produce torque, with a flux the magnitude and phase of which depends on a voltage $P_2 + P_1$, the larger component P_2 of which is derived from the second, while the smaller component P_1 is derived from the first, phase. This exciting and compensating voltage is applied to the rotor by way of the brushes b_3 b_4 and at right angles to the armature axis b_1 b_2 (see Fig. V). The second phase, P_2, is impressed on the armature circuit comprising the brushes b_3 b_4 and the neutralizing winding N_2. The armature ampere-turns produced by this circuit co-operate, to produce torque, with a flux the magnitude and phase of which depend on the voltage $P_1 + P_2$, the greater component P_1 of which is derived from the first, while the smaller component P_2 is derived from the second, phase. This exciting and compensating voltage is applied to the rotor by way of the brushes b_1 b_2 and at right angles to the armature axis b_3 b_4 (see Fig. U). The only difference between the motor shown in Fig. T and that illustrated in the author's Fig. 7, is that the exciting and compensating electromotive forces in the first case are derived from a number of adjustable ratio transformers, whereas in the second they are taken from a polyphase transformer with a movable secondary. While it is possible to alter the phase of the electromotive forces derived from such a transformer, yet their magnitude remains the same for all positions of the movable member, and it then becomes necessary to provide some additional means for the purpose of varying the magnitude of the current. This is done in Fig. 7 by inserting inductances 5 into the exciting circuits. That inductances and not resistances must be used in the exciting circuit of a commutator motor, in order to regulate its speed, has been well known for some time and was clearly set forth in my U.S. Patent No. 960,881, filed December 1906, and based on a prior British application.

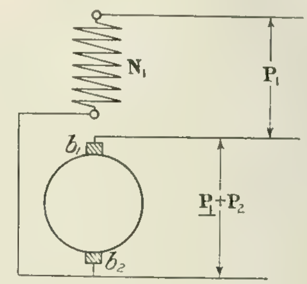


Fig. U.

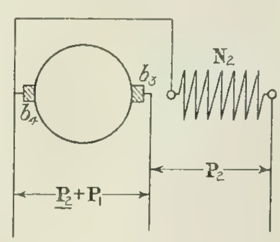


Fig. V.

[illegible]

Fig. X.

[illegible]

I am unable quite to agree with the author's views as to [illegible] such machines operate at or near synchronism, their commutation is as perfect as that of a polyphase motor, all voltages but the reactance voltage being balanced in the [illegible] necessary to take care of the reactance voltage after the latter has reached certain values. Output for output, a

[illegible] described and illustrated [illegible]

With [illegible] whole machine at synchronous speed [illegible] pressure-drop [illegible] Fig. Y. [illegible] the main [illegible] motor principally due to the reactance pressure-drop [illegible] voltage [illegible]

Mr. Shuttleworth.

the pressure-drop due to reactance has increased; this, however, means that the voltage O B₁ impressed on the armature must differ in phase also and subtend an

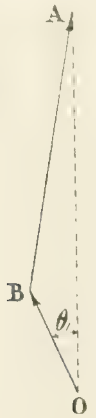


FIG. Y.

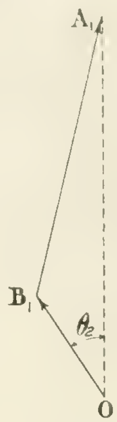


FIG. Z.

angle θ_2 to the star voltage of the motor. Ordinarily the latter voltage would not alter in magnitude or phase, hence the voltages measured on the windings of the motor would be compelled to retain the magnitudes shown in Fig. Y; and to do this it is necessary for the current to depart from unity power factor on other loads so that the impedance pressure-drops can combine with the voltages induced by the field to give the same terminal voltages. To retain good power factor the angle θ must vary with the load, or in other words the exciting voltage must possess two components; one, which is appreciably constant, producing a constant field, rotation in which produces the counter voltage of the motor in phase with the star voltage of the system; and the other, variable, producing a component of the field differing in phase from the former which increases with the load current, rotation in which generates a voltage overcoming the reactance pressure-drop of the load current in the motor. The latter component it will be observed is derived from current transformers connected as shown in Fig. 12.

I have also not previously drawn attention to the fact that if the excitation be applied to the armature of the motor with the method of speed regulation shown, it would seem impossible to accelerate to synchronous speed without actually short-circuiting the armature brushes, and a reversed excitation must be obtained before the short-circuit is opened in order to obtain speeds above synchronism.

My previous reference to the commutation of single-phase motors was made having in mind only the series conduction type, which is the only one used to any appreciable extent in this country. I agree entirely with Mr. Fynn's remarks on this subject.

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THE MAGNETIC BEHAVIOUR OF IRON UNDER ALTERNATING MAGNETIZATION OF SINUSOIDAL WAVE FORM

By N. W. McLachlan, B.Sc. Eng., Associate Member.

[illegible]

[illegible] good when the iron consists of thin sheets such as are [illegible]

[illegible]

Two cases were investigated :

(1) [illegible] round a former, being held in place by an endless spiral spring. The strips were first cut to length approximately, and then shellaced. When the shellac was dry each strip [illegible] netic standpoint the joints were equivalent to lap-joints. The bending of the strips produced a large permanent set, causing a stress in the fibres near the skin of the strip, considerably in excess of the stress at the "yield point."† Tests were made on a core of this form to ascertain what [illegible]

(2) [illegible]

* [illegible]

† [illegible]

from the stamping out were removed, and [illegible] shellac.

[illegible]

No. (1)	
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
Mean diameter of core	[illegible]
No. of turns on primary	[illegible]
No. of turns on secondary	[illegible]
For static field H	[illegible]
For alternating field H_{max}	[illegible]
No. (2)	
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
No. of turns on secondary	= 50
[illegible]	[illegible]
[illegible]	[illegible]

[illegible]

[illegible] then determined ballistically by the method [illegible]

of the galvanometer, which was determined up to the maximum scale readings given by the test rings, was obtained by means of a standard solenoid about 2 metres long, giving 10^6 interlinkages on reversal of a current of 10 amperes. The field of this solenoid is uniform, and the search coil of 84 turns is situated at the middle of its length.

Each point on a B–H curve was the mean of at least three throws, and before each throw the current through the coil was reversed 10 times. Each curve was determined before and after the experiments with alternating currents, and was found to have undergone no change.

Method of obtaining a Sine Wave of Current.

A sine wave of current was obtained by using the circuit shown in Fig. 1. The alternator was designed to give a sine wave of electromotive force *within* 5 per cent up to a load of 10 amperes,* inductive or non-inductive. This being so, it was possible to obtain a sine wave of current by putting a large variable inductance in series with the primary of one of the test rings, each of which was designed to have a comparatively small inductance even at high flux densities. The variable inductance consisted of an Epstein tester with an air core and two choking coils having cores of fine iron wires worked low down on the straight portion of the B–H curve. In addition, the parallel leads from the alternator to the test coil, each lead being about 75 yards long, contributed to the inductance in circuit. The maximum "root mean square" current was 5 amperes, and this necessitated only a portion of the iron cores being within the choking coils, entailing a minimum of interference from hysteresis compatible with the maintenance of a sine wave. For all values of the current a proportionately stiff alternator field was maintained in order to prevent any distortion which might occur due to armature reaction. Variations in the current were effected by adjusting the alternator field and the variable inductance.

In measuring the magnetizing current † the energy component due to hysteresis and eddy currents was included, because the author had not an instrument which would indicate such low powers as those absorbed by the test rings. For the range of values of B used in the experiments the energy loss does not cause any serious alteration. Although the energy current is 90° out of phase with the true magnetizing current, it does not affect the shape of the wave since the former is sinusoidal, and it must therefore be combined with another sine wave of current in order to give the resultant sine wave of current as supplied by the alternator. It is, of course, the latter wave which is recorded by the oscillograph.

Two hot-wire ammeters were used; the first for currents from 0·25 to 1 ampere, and the second for currents from 1 to 5 amperes. Both instruments were standardized frequently during the tests.

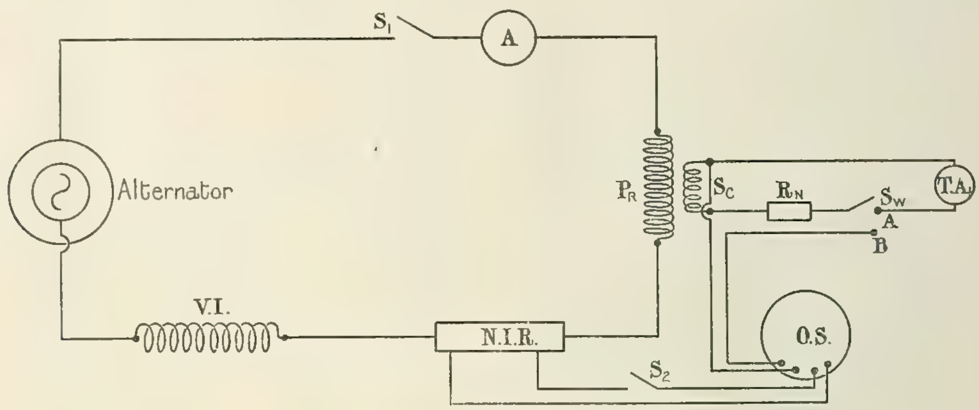


Fig. 1.—Arrangement of Circuit.

A = Hot-wire ammeter.
P_R = Primary of test ring.
N.I.R. = Non-inductive resistance.
V.I. = Variable inductance.
S_C = Secondary of test ring.
$T.A._1$ = Thermo-ammeter.
S_W = Change-over switch.
R_N = Non-inductive resistance box.
O.S. = High-frequency oscillograph.

Method of obtaining the Maximum Flux Density ($B_{max.}$).

The R.M.S. voltage on the terminals of the secondary of a test ring is given by the expression

$$V_{R.M.S.} = 4 f_m B_{max.} a f n \times 10^{-8} \quad . \quad . \quad . \quad . \quad (1)$$

where

f_m is the form factor of the voltage wave $\left(= \frac{\text{R.M.S. value}}{\text{Mean value}}\right)$,

a = cross-sectional area of iron core,

f = frequency in periods per second, and

n = number of turns on secondary of test ring.

By transformation

$$B_{max.} = \frac{V_{R.M.S.} \times 10^{-8}}{4 f_m a f n} \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Since a and n are fixed, it is essential to know the values of $V_{R.M.S.}$ and f_m in order to determine $B_{max.}$ for a given supply frequency.

To ascertain the R.M.S. value of the voltage, a thermo-ammeter (giving a scale reading of 400 mm. for a current of 0·65 milliampere) and a non-inductive resistance box were connected in series with the secondary of a test ring as shown in Fig. 1. The thermo-ammeter was

* In the tests the load never exceeded 5 amperes.

† Referred to in the paper as the "apparent" magnetizing current.

[illegible] little change.

[illegible]

[illegible]

[illegible]

[illegible] critical point as practicable.

To obtain oscillograms the speed of the revolving cylinder carrying the photographic film was adjusted to [illegible] also observed after each photographic record had been secured, this observation acting as a check. The non-inductive resistance, in series with the oscillograph and [illegible]

[illegible] full size.

From these enlargements the "root mean square" and mean values were derived, and hence the form factor.

[illegible] of current flowing from the alternator. The current on the ammeter side of T_1 is sinusoidal, but at T_1 it splits up [illegible] magnetizing current in either shape or phase displacement.

[illegible] and T_1 and the pressure-drop a[illegible] Fig. 1), the current th[illegible]

[illegible]

When T.A.$_1$ had been read it was disconnected from $T_1 T_3$ and put in the secondary circuit to ascertain the pressure-drop. This was the drop due to the apparent magnetizing current, the wave-form of which was not, as stated previously, a pure sine curve. In order to find whether the shape of the wave affected the R.M.S. voltage materially, the oscillograph was disconnected and the pressure-drop measured by T.A.$_1$ when a sine wave of current was sent through the circuit equal in value to that passing through the primary at the time the oscillograms were taken.* The difference in voltage was found to be between 2 and 3 per cent, being larger when the current was sinusoidal.

A mathematical investigation into the shape of the apparent magnetizing current wave, when the oscillograph current was appreciable, showed that since the effects of harmonics higher than the third were of small account, the current could be represented by the equation

$$i_{am} = A_0 \left\{ \sin\theta - 0{\cdot}03 \sin 3(\theta + \alpha) \right\}$$

where i_{am} = apparent magnetizing current,
and $\theta = 2\pi f t$.

The maximum alteration in the form factor of the apparent magnetizing current, as obtained from the above equation, is ± 1 per cent.

TABLE 1.

(*Ring No. 1, $f = 50$ Periods per Second.*)

Apparent Magnetizing Force $H_{max.}$	Volts on Terminals of Secondary $V_{R.M.S.}$	Form Factor $f_m = \frac{V_{R.M.S.}}{V_{mean}}$	Maximum Flux Density in Iron $B_{max.}$ Static Field (Apparent) B_s	Alternating Field B_A	$f_a = \frac{V_{max.}}{V_{R.M.S.}}$	Ratio of $V_{R.M.S.}$ when Current is a Sine Wave to $V_{R.M.S.}$ when Voltage is a Sine Wave, for same Value of $B_{max.}$ $= f_m/1{\cdot}11$	Ratio of $V_{max.}$ when Current is a Sine Wave to $V_{max.}$ when Voltage is a Sine Wave for same Value of $B_{max.}$ $= f_a/1{\cdot}414$
0	0	1·11	0	0	1·41	1·0	1·0
2·5	0·234	1·26	5,500	6,100	1·79	1·14	1·27
4·69	0·403	1·54	7,900	8,600	2·35	1·39	1·66
7·36	0·532	1·72	9,400	10,200	2·97	1·55	2·1
8·38	0·588	1·78	10,200	10,900	3·18	1·6	2·25
12·6	0·724	1·94	11,600	12,300	3·54	1·75	2·5
17·2	0·823	2·02	12,500	13,400	3·85	1·82	2·72
25·4	0·948	2·15	13,400	14,500	4·24	1·94	3·0
32·9	1·05	2·28	13,900	15,100	4·62	2·05	3·27
42·1	1·142	2·4	14,400	15,600	4·9	2·16	3·46

TABLE 2.

(*Ring No. 2, $f = 50$ Periods per Second.*)

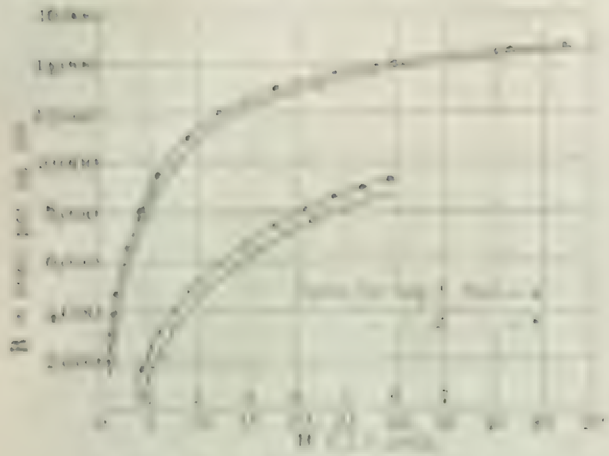
Apparent Magnetizing Force $H_{max.}$	Voltage at Terminals of Secondary for same Area of Iron and Secondary Turns as Ring 1 $V_{R.M.S.}$	Form Factor $f_m = \frac{V_{R.M.S.}}{V_{mean}}$	Maximum Flux Density in Iron $B_{max.}$ Static Field (Apparent) B_s	Alternating Field B_a	$f_a = \frac{V_{max.}}{V_{R.M.S.}}$	Ratio of $V_{R.M.S.}$ when Current is a Sine Wave to $V_{R.M.S.}$ when Voltage is a Sine Wave, for same Value of $B_{max.}$, $= f_m/1{\cdot}11$	Ratio of $V_{max.}$ when Current is a Sine Wave to $V_{max.}$ when Voltage is a Sine Wave for same Value of $B_{max.}$, $= f_a/1{\cdot}414$
0	0	1·11	0	0	1·414	1·0	1·0
2·27	0·25	1·29	5,700	6,400	1·84	1·16	1·3
4·96	0·474	1·63	8,800	9,600	2·67	1·47	1·89
7·39	0·601	1·77	10,400	11,200	2·92	1·59	2·06
13·6	0·806	1·99	12,400	13,300	3·4	1·77	2·4
18·3	0·9	2·1	13,000	14,100	3·74	1·89	2·64
29·4	1·07	2·31	13,900	15,200	4·06	2·08	2·87
42	1·215	2·53	14,500	15,800	4·49	2·28	3·17

RESULTS OF EXPERIMENTS.

On reference to Tables 1 and 2 and Fig. 3, it will be seen that when the magnetization is produced by a steady current the flux density in the iron, for the same value of H, is greater when the core consists of complete discs free from mechanical stress due to bending, than when the core is built up of strips, the ends of which butt together. The diminution in flux density is to be attributed chiefly to the small air-gaps at the extremities of the strips (see

* The value of this current was found by calculation from the pressure-drop across S_H.

[illegible]



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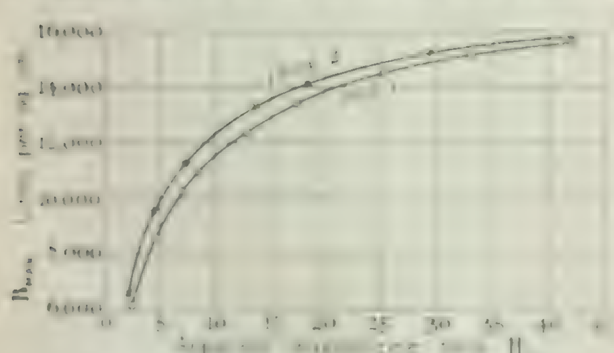


[illegible]

the hysteresis loss, which is paramount since the eddy currents at low inductions in such thin sheets are very small. Owing to the shape of the voltage wave being [illegible] ...sities, the form factor [illegible]

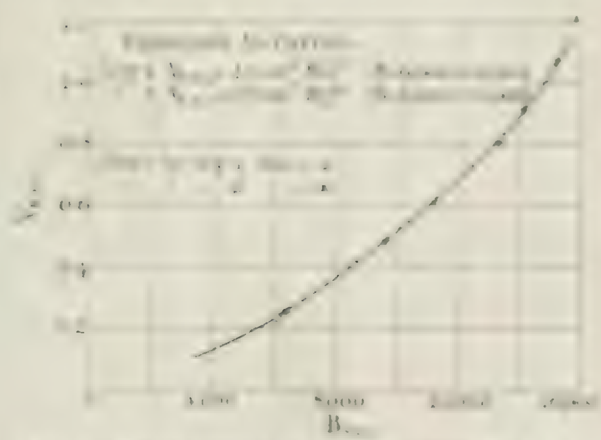
[illegible] circuit, [illegible] ...lts of some of the [illegible]

[illegible] values given in the table. The first set of readings shows [illegible]

[illegible]

[illegible]

[illegible] duce a certain value of B is comparatively large [illegible]



[illegible]

[illegible] current magnetization would be still greater if the energy [illegible] between the B–H curves for static fields is very similar to that for alternating fields.

[illegible]

which were obtained from Figs. 6 and 7, are given below and are of the form $V = cB^n$, n being greater than unity. If the voltage wave had been a sine curve the R.M.S. voltage would have been proportional to $B_{max.}$ since the form factor in this instance is constant and equal to 1·11.

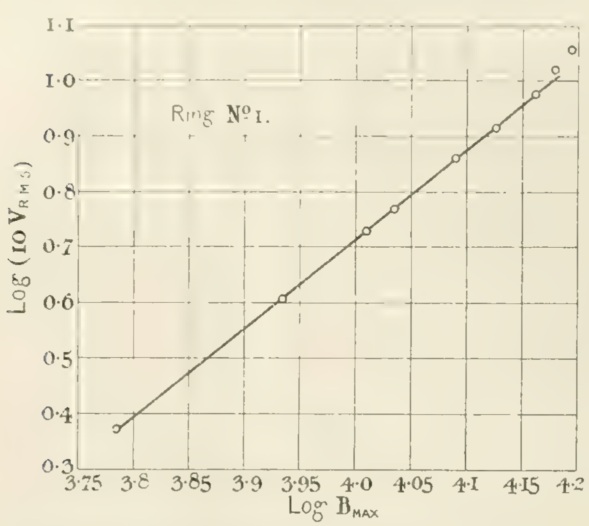


FIG. 6.—Log (10 $V_{R.M.S.}$) plotted against log ($B_{max.}$).

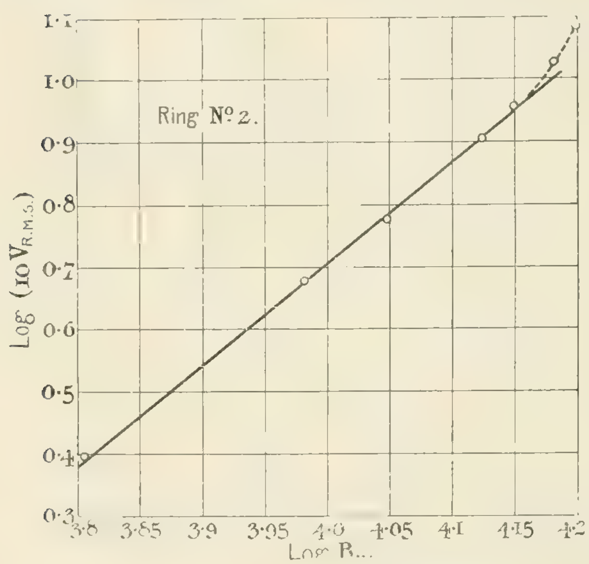


FIG. 7.—Log (10 $V_{R.M.S.}$) plotted against log ($B_{max.}$).

$$V = cB^n \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

From Equation (1) $V = 4 f_m B a f n \times 10^{-8}$;

$$\therefore 4 f_m B a f n \times 10^{-8} = c B^n ;$$

$$\therefore f_m = \frac{c B^{n-1} \times 10^8}{4 a f n} = k B^{n-1}, \text{ where } k = \frac{c \times 10^8}{4 a f n}.$$

Hence throughout the range covered by Equation (3) the form factor may be expressed in terms of the maximum flux density. By adopting the above mode of procedure the following equations were derived :

$f_m = 5·59 \times 10^{-3} B^{[illegible]}$ ($B_{max.}$ = 6,000 to 14,500) . Ring No. 1.

$f_m = 5·1 \times 10^{-3} B^{0·63}$ (B_{max} = 6,000 to 14,000) . Ring No. 2.

When B is less than 6,000 the index gradually decreases until when B = 0 it is equal to zero, while the constant gradually increases until it becomes 1·11, the form factor for a sinusoidal wave.

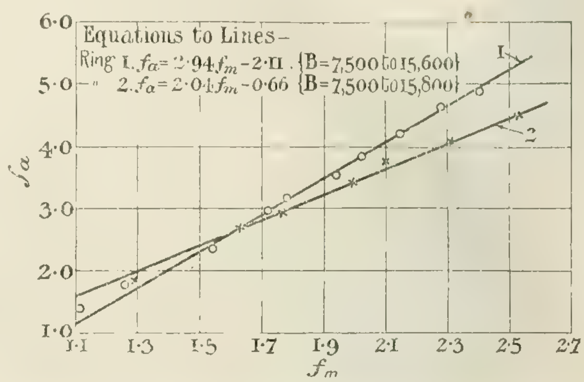


FIG. 8.—$f_a \left(= \frac{V_{max.}}{V_{R.M.S.}} \right)$ plotted against the form factor f_m.

It is evident from an inspection of the oscillograms in Figs. 9 to 13 that for low values of B the form factor is augmented by hysteresis, and for high values of B by hysteresis and eddy currents, especially the latter. The form factor for the same value of $B_{max.}$ is very similar for rings 1 and 2. For large values of $B_{max.}$ the form factor for ring 2 is somewhat larger than for ring 1, owing in all probability to increased eddy-current effect brought about by the difference in the thickness of the plates, as the plates in ring 2 are 9 per cent thicker than those in ring 1. Fig. 8 shows $f_a (= V_{max.}/V_{R.M.S.})$ plotted against the form factor. The points are nearly collinear from B = 7,500 to B = 15,800 and the equations to the respective lines are given. By substituting the values for f_m in the equations immediately preceding, the relationship between f_a and $B_{max.}$ for the forementioned range may be derived.

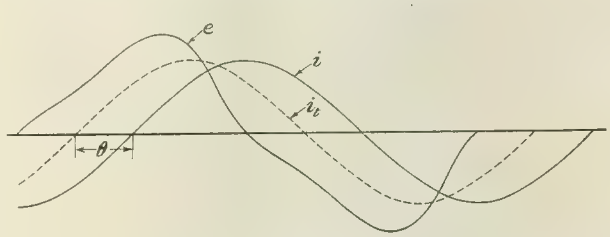


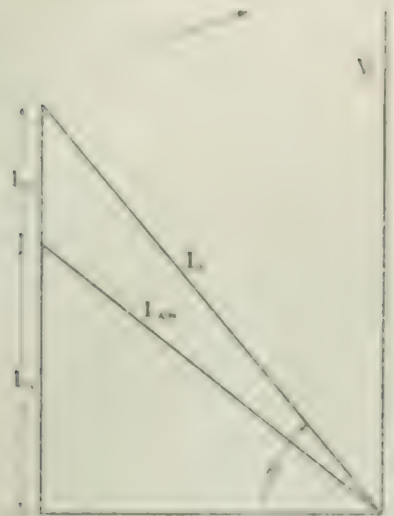
FIG. 9.

Ring 2. $f = 50 \sim$; $B_{max.}$ = 2,000 ; form factor = 1·14. Current a sine wave.*

The last two columns in Tables 1 and 2 are worthy of notice since they indicate the increase in the R.M.S. and maximum voltages over the same quantities obtained when the magnetizing current produces a sine wave of voltage. Curiously enough the *voltage* wave under the type of

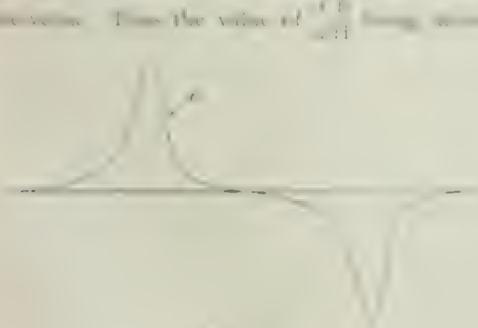
* The displacement of the current wave (shown dotted) from its correct position is due to the oscillograph and energy currents being large in comparison with the true magnetizing current. Fig 9A shows the vector diagram for this case, on the assumption that the current and voltage waves are sinusoidal. The full-line curve (i) shows the probable position of the current wave provided that the effect of the oscillograph and energy currents was negligible, *i.e.* $\theta = 0$.

[illegible]



[illegible]

[illegible] is small compared with that when the current is sinusoidal, [illegible]



[illegible]

[illegible] sine curve. Hence the voltage wave is peaked and its [illegible]

[illegible] greater for a sinusoidal magnetizing current than for the [illegible]

[illegible]

[illegible]

[illegible]

[illegible] larger [illegible]

Oscillograms showing the voltage wave-forms corresponding to various flux densities are given in Figs. 9 to 13. At low flux densities the maximum voltage is shifted forwards due to hysteresis, the curve being asymmetrical about a vertical axis through the maximum value. As the flux density increases, the maximum value approaches nearer to the centre of the half wave-length, the wave becoming more nearly symmetrical about a vertical axis through the maximum value. In all cases each half wave has two points of inflexion (apart from those where the voltage is zero), one on each side of the maximum value. These occur, (1) when the voltage is small, (2) when the voltage is large. In Fig. 13 the points in question are marked α and β.

When the shape of the current wave departed from a sine curve the voltage across the secondary dropped in value. Figs. 14 to 17 show the voltage and current waves obtained, and Table 4 gives a comparison with the data derived for sinusoidal magnetizing current.

Experiments carried out at frequencies lower* than 50 periods per second showed that for sinusoidal and approximately sinusoidal magnetization the secondary voltage was proportionately greater than at 50 periods per second. Some of the results are shown in Table 5.

If the slight increase in the true magnetizing current at lower frequencies (due to smaller energy current) is taken into account, the difference between the value at 50 periods and the values for lower frequencies is small enough to be negligible.

The author was unable to ascertain if the form factor underwent alteration at frequencies lower than 50 periods per second. It is very improbable that the form factor would alter as much as 7 per cent (see Table 5). Thus due to the proportionate increase in the R.M.S. voltage, the

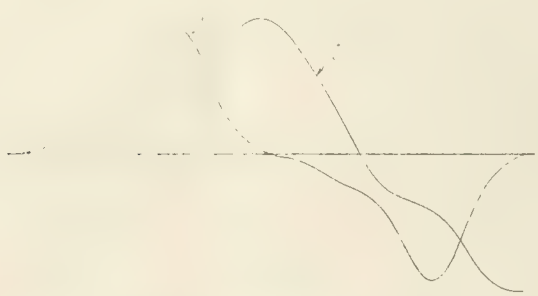


FIG. 14.

Ring 1. $f = 50 \sim$: $B_{max.} = 7{,}600$ approximately. Current, approximately sinusoidal.

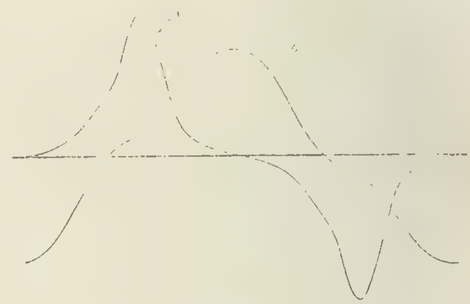


FIG. 15.

Ring 1. $f = 50 \sim$: $B_{max.} = 11{,}700$ approximately. Current, approximately sinusoidal.

TABLE 4.

$f = 50$ Periods per Second. Ring No. 1.

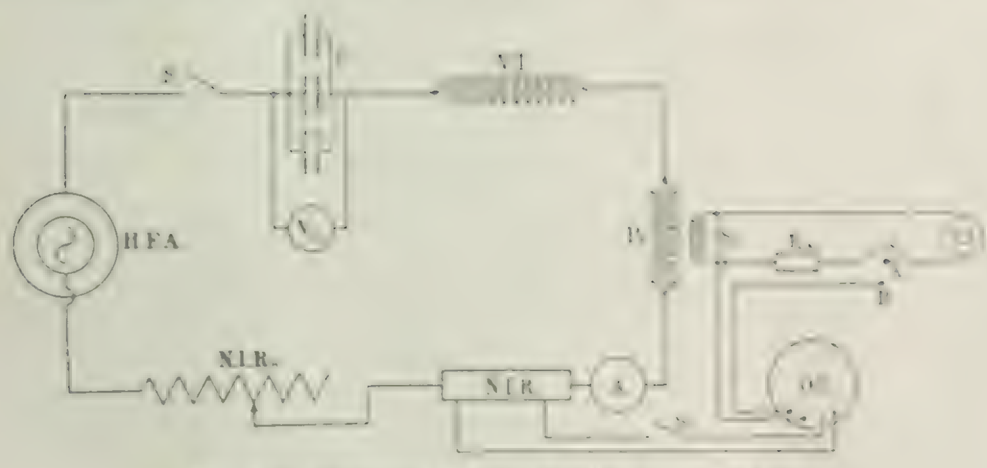
Shape of Current Wave	Apparent Value of $H_{max.}$	R.M.S. Voltage on Secondary	Form Factor f_m.	Max. Flux Density $B_{max.}$ Static (Apparent)	Max. Flux Density $B_{max.}$ Alternating
Sine	42	1·142	2·4	14,400	15,600
As in Fig. 17	42	0·82	1·83	14,400	14,700

TABLE 5.

Ring No. 1.

Shape of Current Wave	Apparent Value of $H_{max.}$	R.M.S. Voltage on Secondary	Frequency	Proportionate Increase in $V_{R.M.S.}$ at 25 periods
Sine	42	1·142	50	7 per cent
,,	42	0·611	25	
As in Fig. 17	42	0·82	50	5·4 per cent
,,	42	0·432	25	

* The lowest frequency attained was 5 periods per second.


S
H.F.A.
N.I.R.
A

electromagnetic effect of eddy currents, the value of $B_{max.}$ has been reduced 27 per cent.

Mention has not been made hitherto of the energy components 90° out of phase with the true magnetizing currents. It was thought unnecessary to introduce the energy components into the foregoing calculations, because they would not have affected the results materially. However, it may be remarked that the energy loss in the iron was measured (at 500 periods per second and H apparent = 33·2) and reached the high figure of 250 watts per kilogram. Since this gave a calculated temperature rise of 1 degree C. per second (neglecting radiation) the iron soon became very warm, and it was imperative to obtain the thermo-ammeter reading as quickly as possible.

Conclusions.

1. That the bending of thin plates of Lohys, resulting in the production of a large permanent set does not affect the magnetic properties to any appreciable extent when the magnetization is produced by a steady current. The permeability is lower at small flux densities, this being due to the joints in the strips whereby slight air-gaps are introduced.* The permeability is affected in the same way and due to the same cause when the magnetization is produced by an alternating current of sinusoidal wave-form. In this case there is an increase in the hysteresis loss due to mechanical stress.†

2. That when the magnetization is produced by an alternating current of sinusoidal wave-form, it was found :—

(*a*) That the permeability is greater than the permeability obtained with static fields. This phenomenon was observed in the foregoing experiments from $B_{max.} = 700$ to $B_{max.} = 16{,}000$ lines per square centimetre.

(*b*) That for all values of the flux density in the iron up to 16,000 lines per square centimetre the form factor and the ratio of the maximum and R.M.S. voltages are greater than the corresponding quantities when the voltage wave-form is sinusoidal, by an amount depending on and increasing with the maximum flux density. The following laws were obtained :—

Ring 1. $f_m = 5{\cdot}59 \times 10^{-3} B_{max.}^{0{\cdot}62}$ ($B_{max.} = 6{,}000$ to 14,500.)
Ring 2. $f_m = 5{\cdot}1 \times 10^{-3} B_{max.}^{0{\cdot}63}$ ($B_{max.} = 6{,}000$ to 14,000.)

Ring 1. $f_a = 2{\cdot}94 f_m - 2{\cdot}11$. ($B_{max.}$ 7,500 to 15,600.)
Ring 2. $f_a = 2{\cdot}04 f_m - 0{\cdot}66$. ($B_{max.}$ 7,500 to 15,800.)

(*c*) That the R.M.S. and maximum values of the voltage are larger than those obtained when the voltage wave is sinusoidal by an amount depending on and increasing with the maximum flux density. The following laws were obtained :—

Ring 1. $V_{R.M.S.} = 1{\cdot}7 \times 10^{-7} B_{max.}^{1{\cdot}72}$ (B=6,000 to 14,500.)
Ring 2. $V_{R.M.S.} = 1{\cdot}55 \times 10^{-7} B_{max.}^{1{\cdot}63}$ (B=6,000 to 14,000.)

(*d*) That for frequencies up to 500 periods per second the R.M.S. voltage is higher than that when the voltage wave is sinusoidal, but the lowering of the maximum flux density due to eddy currents is very prominent.

3. That when the magnetization is produced by a current the wave-form of which is approximately sinusoidal (such as is shown in Fig. 17), conclusion 2, (*a*, *b*, and *c*) is applicable.* The difference between these results and those obtained when the voltage wave is sinusoidal is not so marked as the difference between the latter results and those obtained when the *current* is sinusoidal.

4. That whether the current be sinusoidal or approximately sinusoidal (Fig. 17) the R.M.S. voltage across the secondary coil is proportionately higher at 25 periods per second than at 50 periods per second for a given magnetizing current. (This was tested down to a frequency of 5 periods per second with the same result.)

Finally, the author wishes to express his sincere thanks to Professor E. W. Marchant, D.Sc., for the valuable help and criticism which he has given during the preparation of the paper, also for the use of the apparatus in the Electrical Engineering Laboratories of the Liverpool University where the experiments were conducted.

APPENDIX.

If there had been no permanent set due to the bending of the strips in Ring 1, the maximum stress, which occurs at the skin of the strip, would have been within the elastic limit. In this case the formula $f = Ey/R$, where f = intensity of stress at the skin of the strip whether tensile or compressive, E = Young's modulus of elasticity, y = half thickness of strip, and R = radius of curvature to which centre of strip is bent, would have been applicable.

Presuming for the present that there was no permanent set, the strip remaining perfectly elastic during the bending, the skin stress in the innermost strip would be

$$f = \frac{30 \times 10^6 \times 0{\cdot}0165}{4{\cdot}55} = 108{,}000 \text{ lb. per square inch.}$$

The stress diagram for the section would be of the form illustrated in Fig. 18.

As the ultimate strength of Lohys is only 40,000 lb. per square inch, it is quite clear that the actual case is not akin to that cited above, and moreover the skin stress could not possibly be in excess of 40,000 lb. per square inch. Consequently the real stress diagram is not the

* Messrs. Campbell and Booth have shown that the permeability of iron strips is diminished by bending which produces permanent set. The effect is most pronounced with a hard material such as silicon iron. With soft transformer iron the effect is much less pronounced. The results given are for cases in which the diminution in permeability is most marked. In all the above instances the ends of the strips overlapped and were firmly clamped together, thereby practically ensuring continuity of the ring. (A. CAMPBELL and H. C. BOOTH. On errors in magnetic testing due to elastic strain. *Proceedings of the Physical Society of London*, vol. 25, p. 102, 1912-13.)

In the present instance it is impossible to state with accuracy (owing to the presence of the joints) the extent to which the bending of the strips influences the permeability. Conclusion (1) has been based on : (*a*) Comparison with the results obtained with complete discs of Lohys ; (*b*) the assumption that the material was the same quality in both rings ; (*c*) the fact that Lohys is a soft iron ; (*d*) Ewing's tests on bars and on the effects of tension and compression.

† The increase in the total loss per kilogram is about 3 per cent when $f = 50$ periods and $B_{max.} = 15{,}500$. The losses are not strictly comparable owing to the plates in ring 2 being 9 per cent thicker than those in ring 1. If the plates had been the same thickness in each case the eddy-current loss in ring 2 would have been reduced by 18 per cent, and the increase in the total losses would have exceeded 3 per cent. Assuming that the eddy-current loss in ring 1 is not appreciably affected by bending, the increase in the total losses is chiefly due to an increase in hysteresis caused by mechanical stress.

* Laws were not determined in this case owing to the difficulty of ensuring that the shape of the current wave was similar for all values thereof.

steel in the ductile stage, it is clear that the diagram

bourhood of the neutral surface. Thus the strip is practically equivalent to two straight parallel bars, one in

smaller for weak fields than those for the uncut bar while those for strong fields do not differ materially. This has

foregoing argument

INCREMENTAL ARMATURE COPPER LOSSES AT NO-LOAD AND ARMATURE TEETH EDDY-CURRENT LOSSES.

By A. PRESS, B.Sc.

(*Paper first received* 15 *January*, 1914, *and in final form* 21 *April*, 1915.)

When any solid conductor passes through a variable magnetic field the various lateral portions of the conductor have slightly different voltages induced in them, thereby giving rise to eddy-current losses. A result of this will be that the observed no-load input to overcome the losses in a locked unwound rotor of an induction motor will be manifestly different from the observed losses with the same locked rotor having a solid open-circuited bar winding.

In the case of a dynamo, in addition to an eddy-current loss set up by the self-induction field * at right angles to the main field, there is an eddy-current loss set up by the main field itself; the latter loss is independent of any load and is only dependent upon the main-field density in the slots and the speed of rotation.

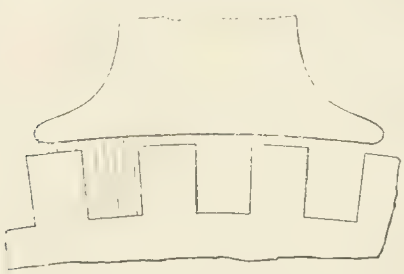


FIG. 1.

The object of this paper is to give formulæ and curves for estimating this incremental copper loss so that such data may be available for the designers in dealing with very small and also very large armatures.

As a first approximation it will be assumed that the flux enters the slots perpendicularly. However, since the same method is really applicable to the determination of the eddy-current losses induced in the teeth themselves (assuming constant permeability), the one solution can be made available for both cases.

The laminations are considered as extending in the direction of the (x, y) plane with the flux passing into the laminations (or the slot copper) in the direction y, at right angles to the (x, z) plane. Assuming a sine-wave distribution of magnetic flux from the poles into the armature, the density B in gausses with respect to any point in the armature teeth (or slot conductor) can be said to be given by the expression

$$B = B_0 \sin (p\,t + \pi\,x/\mathfrak{T}) \quad . \quad . \quad . \quad . \quad . \quad (1)$$

* This loss was first investigated by A. B. Field [A. B. FIELD. Eddy currents in large slot-wound conductors. *Transactions of the American Institute of Electrical Engineers*, vol. 24, p. 761, 1905.] Also W. ROGOWSKI. Über zusätliche Kupferverluste . . . einer Wechselstrommaschine. *Archiv für Elektrotechnik*, vol. 2, p. 81, 1913–14.

where $\mathfrak{T}$ is the pole-pitch in centimetres and B_0 is the maximum magnetic density in the teeth air-gap (or in the air-gap of the slots). Thus two pole-pitches constitute a cycle. Obviously the flux density at any point of the teeth or slots is a function of the time as well as of the position of such point with respect to the origin, as indicated in Fig. 2. The field is assumed to be a moving one and the armature to be stationary.

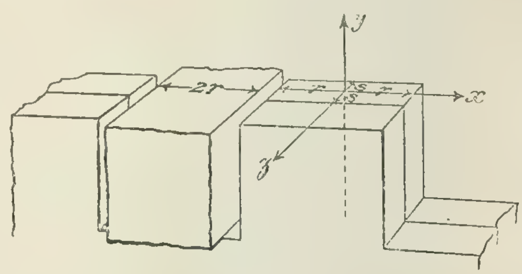


FIG. 2.

If δ_z, δ_x are the eddy-current densities in amperes per square centimetre in the corresponding directions z and x of the teeth laminations (or slot copper), we have by the usual equations of Heaviside or Hertz

$$\frac{4\pi}{10}\delta_z = \frac{d\,H_y}{d\,x} = \frac{1}{\mu}\cdot\frac{d\,B}{d\,x}$$

$$\frac{4\pi}{10}\delta_x = -\frac{d\,H_y}{d\,z} = \frac{1}{\mu}\cdot\frac{d\,B}{d\,z}$$

$$-\frac{d\,B}{d\,t}\cdot\frac{10^{-8}}{\rho} = \frac{d\,\delta_x}{d\,z} - \frac{d\,\delta_x}{d\,x}$$

The latter equations are in the usual engineering metric units. It follows from the above that

$$\frac{4\pi\mu}{10^9\rho}\cdot\frac{d\,B}{d\,t} = \frac{d^2\,B}{d\,x^2} + \frac{d^2\,B}{d\,z^2} \quad . \quad . \quad . \quad . \quad (2)$$

However, employing the Heaviside operator $q^2 = \frac{4\pi\mu}{10^9\rho}\cdot\frac{d}{d\,t}$ the equation becomes

$$\frac{d^2\,B}{d\,x^2} + \frac{d^2\,B}{d\,y^2} = q^2\,B.$$

Since B is a sine function of the time, by Equation (1) we have

$$i = \sqrt{-1} = \frac{1}{p}\frac{d}{d\,t}, \quad \text{and} \quad \frac{d^2\,B}{d\,x^2} + \frac{d^2\,B}{d\,z^2} = k\,i\,p\,B \quad . \quad (3)$$

where k stands for $4\pi\mu/10^9\rho$.

provided we write

ing current in phase will then be the measure of the eddy-current losses in the volume $4\,rs$ cubic centimetres of the material of the laminations.

This really follows from the consideration that the eddy currents set up a cross flux which, because of the main flux threading the rectangle, causes by Lenz's law an attraction between the two magnetic fluxes which is expressed by a mechanical torque. Obviously the same mechanical torque will be set up by the replaced equivalent peripheral circuit along the edges of the rectangle $2\,r \times 2\,s$ provided that the cross flux set up at right angles to the main flux is the same. In both cases the mechanical activity to overcome the eddy-current losses is dissipated into the same quantity of Joulean waste.

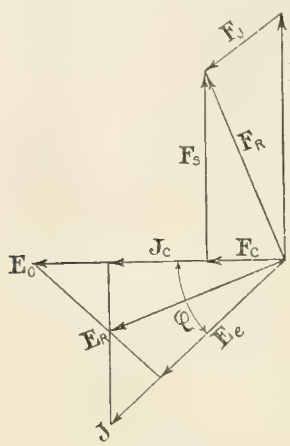


FIG. 3.

To simulate entirely the flux reactions, a resistance and reactance can be assumed intercalated into the peripheral circuit. A vector diagram (Fig. 3) will serve to clarify the ideas expressed.

Let F_0 = open-circuit peripheral flux, setting up
- E_0 = open-circuit voltage at right angles to F_0,
- F_R = actual resultant flux passing through the closed peripheral circuit, setting up
- E_R = actual resultant voltage in peripheral circuit; setting up
- J = actual current in peripheral circuit, with proper amount of resistance and reactance intercalated into the circuit, to produce the mechanically-equivalent flux reactions,
- E_e = actual component of voltage E_R in phase with the current J of the peripheral circuit,
- F_J = component of flux set up by, and in phase with the current J, combining with the open-circuit flux F_0, to give the actual resultant threading flux F_R.

The eddy-current loss in watts per $4\,rs$ cubic centimetres, using effective or R.M.S. values, is evidently given by $J\,E_e$, but this can be replaced by the relation $J_c\,E_0$, because

$$E_e/E = \cos\varphi = J_c/J.$$

Hence $$4\,rs\,W = J_c\,E_0.$$

Here W is the watts per cubic centimetre of the laminations, J_c is the effective current necessary to set up the amplitude of flux F_c, and E_0 is the effective voltage set up in the peripheral circuit with an open-circuit flux amplitude

$$B_0\,\frac{4\,s\,\mathfrak{T}}{\pi}\sin\frac{\pi\,r}{\mathfrak{T}}$$

of Equation (5).

Obviously to set up the flux F_c to thread the peripheral circuit to a depth of 1 centimetre

$$\frac{4\,\pi}{10}\sqrt{2}\,J_c = \frac{B_c}{\mu},$$

which gives $$J_c = \frac{10}{4\,\pi\,\mu\,\sqrt{2}}\cdot\frac{F_c}{4\,r\,s},$$

or by substitution for the component F_c

$$J_c = \frac{10}{4\,\pi\,\mu\,\sqrt{2}}\cdot B_0\,(R_1\,\mathfrak{T}_N + R_2\,\mathfrak{T}_{M'})$$

The effective volts on the other hand, E_0, are given by

$$E_0 = \frac{F_0 \times 10^{-8}\,p}{\sqrt{2}} = \frac{p}{\sqrt{2}}\cdot B_0\cdot\frac{4\,s\,\mathfrak{T}}{\pi}\cdot\sin\frac{\pi\,r}{\mathfrak{T}}\cdot 10^{-8}.$$

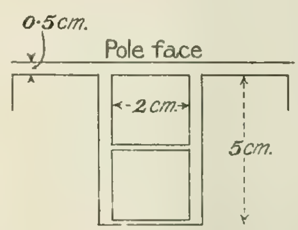


FIG. 4.

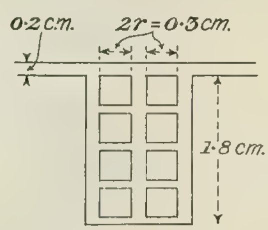


FIG. 5.

Hence the eddy-current loss per cubic centimetre of the laminations is given by

$$W = \frac{\sim B_0^2}{4\,\pi\,\mu}\cdot\frac{\mathfrak{T}}{r}\cdot\sin\frac{\pi\,r}{\mathfrak{T}}\cdot(R_1\,\mathfrak{T}_N + R_2\,\mathfrak{T}_{M'})\,10^{-7} \quad . \quad (6)$$

This formula is the solution desired for the losses in the teeth, and applies as well to wide slot-wound armature conductors.

The formula simplifies greatly when it is observed from Fig. 2 that for the case of the slot copper, $2\,r$ in the formula is to be taken as the width of any individual conductor in the slot, and $2\,s$ as practically approaching infinity in value. In this case

$$a_n = b_n = \frac{\pi}{2\sqrt{2}}\,r\sqrt{\frac{16\,\mu\,p}{10^9\,\rho\,\pi}}$$

$$a_m = b_m = \infty\,; \quad \mathfrak{T}_m = 0 = \mathfrak{T}_{M'}$$

and the term $R_2\,\mathfrak{T}_{M'}$ disappears since it approaches zero. Moreover, because $a_n = b_n$, it follows that we have the following reduction :—

$$\mathfrak{T}_N = \sum_{1\,3\,5}\frac{1}{n^2}\,\mathfrak{T}_n = \frac{\pi^2}{8}\cdot\left(\frac{1}{2\,a_n}\,\frac{\sinh 2\,a_n - \sin 2\,a_n}{\cosh 2\,a_n + \cos 2\,a_n}\right)$$

[illegible]

[illegible]

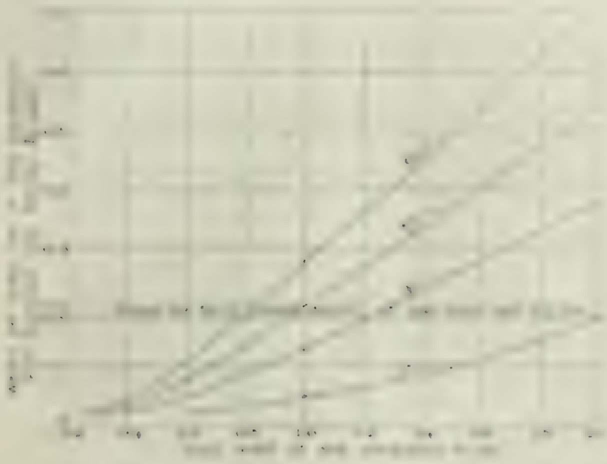


FIG. 6.

It can be shown for all practical purposes [illegible]

$$\frac{2c}{\tau} < 0{\cdot}2.$$

[illegible]

APPLICATIONS.

Example 1.—Assuming the slot and conductor dimensions [illegible]

as against the 1,000 of the standard curves.

[illegible]

current loss.

FIG. 7.

[illegible]

SOME NOTES ON THE COOLING OF CONDENSING WATER.

By C. S. JEFFREY, Associate Member.

(*Paper read before the* CALCUTTA LOCAL SECTION 25 *February*, 1915.)

ABSTRACT.

Very little information has been published regarding the artificial cooling of condensing water and the subject appears not to have received much scientific attention. The problems connected therewith have only become of importance in recent years and date from the advent of the steam turbine, in which high vacuum, with a correspondingly low temperature of the condenser discharge water, is essential to efficiency. In hot and humid countries the difficulties are much greater than in temperate climes, and practical experience gained in the latter is of comparatively little value in tackling the problems of the tropics. The author has endeavoured in this paper to show the effect of climatic conditions on the rate of water cooling, and to suggest a method for the further investigation of the subject.

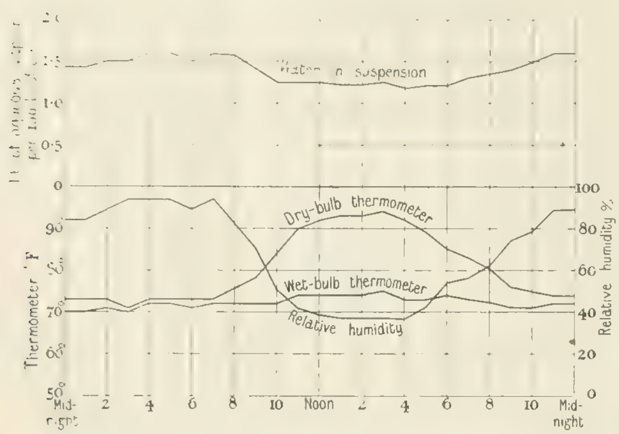


FIG. 1.—Atmospheric Temperature—Humidity Curve, Rangoon, 12 April, 1914.

The investigations described were made in Rangoon under the meteorological conditions given in Table 1 and Figs. 1 and 2.

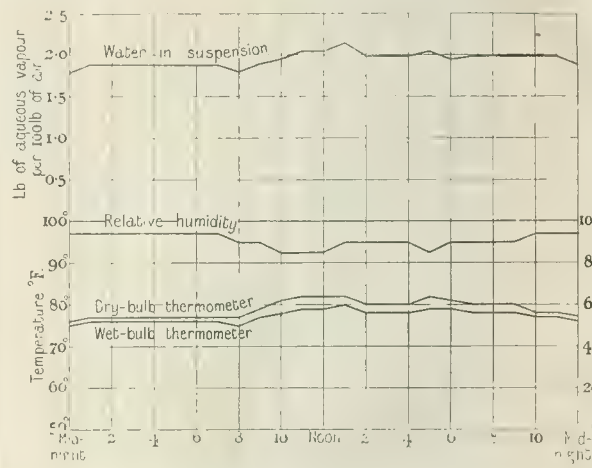


FIG. 2.—Atmospheric Temperature—Humidity Curve, Rangoon, 18 August, 1914.

Total rainfall in 24 hours—2·98 inches.

The readings given in Table 1 were taken during 1913–14. The shade temperature and wind velocity were taken from the published records of the Rangoon Port Commissioners. The other observations (with the exception of solar radiation, which is estimated from the only available Indian records, those made in Simla) were

TABLE 1.

	Shade Temperature. °F.			Approx. Mean Solar Radiation B.Th.U. per sq. ft. per hour	Relative Humidity, per cent			Mean Weight of Water in suspension in 100 lb. of Air. lb.	Earth Temperature. °F.		Mean Wind Velocity ft. per min.
	Max.	Min.	Mean		Max.	Min.	Mean		Max.	Min.	
January	79·9	65·7	70·4	40	88	44	80	1·28	82	77	—
February	84·3	66·6	72·5	50	83	42	75	1·27	83	81	427
March	87·3	71·4	76·7	60	85	46	65	1·17	86	84	663
April	90·8	74·4	81·3	70	89	44	65	1·56	91	88	855
May	89·7	77·0	80·0	60	84	65	74	1·63	89	86	652
June	84·7	75·4	78·5	10	92	86	88	1·76	84	82	750
July	84·2	75·3	78·3	10	95	85	89	1·78	83	81·5	905
August	82·0	75·3	77·6	10	95	80	88	1·74	81	79	767
September	82·0	74·2	76·9	20	90	76	85	1·70	83	81	545
October	81·8	78·2	79·4	30	85	75	80	1·76	83	81	355
November	81·7	71·7	75·1	20	90	44	82	1·48	82	80	387
December	81·7	68·1	72·6	30	95	46	80	1·46	82	80	394

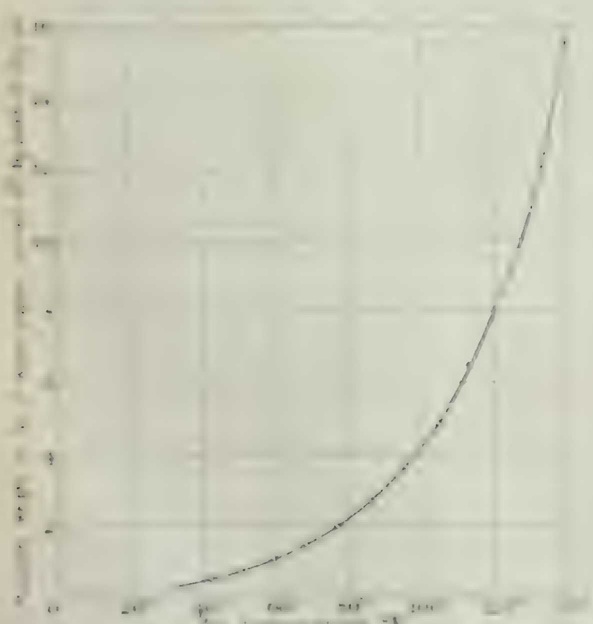


FIG. 3.

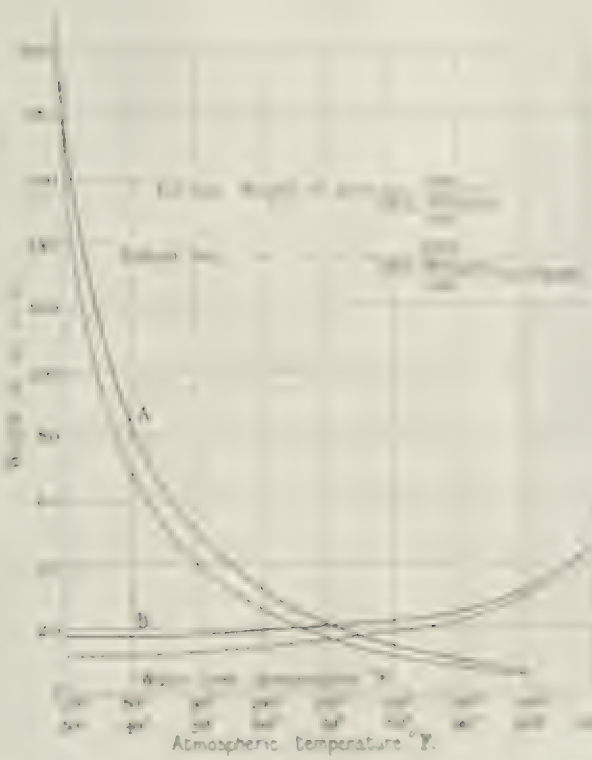


FIG. 4.

the heat required to raise the temperature of the air is neglected.

It should be noted that hypothetically the final temperature of the water relative to the atmospheric temperature does not affect the quantity of air required for the dissipation of any given number of heat units; whereas in practice it does, because in cooling to a very low temperature it is not possible to make the air leave the tower saturated and at the temperature of the inlet water without increasing the height and area disproportionately. By increasing the size of the tower the water can be cooled down to the temperature of the wet-bulb thermometer, but the capital and running costs would be prohibitive with such an arrangement. The aim of the designer of a cooling tower is to secure the maximum cooling effect by bringing the air and water into intimate contact, or in other words to present the greatest possible water surface to the air.

The height at which the water is delivered to a closed-type cooling tower should be sufficient to ensure that the air leaves the outlet at the temperature of the inlet water and as nearly as possible at 100 per cent relative humidity. Beyond this there is no advantage in increasing the height.

Cooling Ponds.

Cooling ponds have not received much attention from engineers, the reason probably being that most electricity supply stations are situated near the centre of the area of supply where the cost of ground is prohibitive or where the surrounding buildings effectually interrupt the free circulation of air which is necessary if any degree of efficiency is to be attained.

Cooling ponds and natural-draught open-type cooling towers are essentially the same as regards the principle on which they operate, and they both have the same disadvantage that no control of the cooling effect is possible, as it is entirely dependent on climatic conditions. In these types of apparatus as large a water surface as possible is exposed to the atmosphere. It is possible with a tower to present an area of water surface to the wind which would be quite impracticable in a pond, but that can only be done with a considerable expenditure of power. In what follows, the results obtained per square foot of pond area may be applied to open-type coolers per square foot of exposed water surface.

The choice between a natural-draught open-type tower and a cooling pond will depend upon the relative cost. If the interest on the capital cost of the cooling tower plus the cost of the extra pumping, depreciation, and maintenance, exceeds the interest on the capital cost of a cooling pond plus the cost of maintenance, then the cooling pond should be selected. In other words the principal charge in running a cooling apparatus is usually the cost of pumping. The efficiency of a natural-draught open-type tower, taking into consideration only the number of heat units dissipated per unit of power used for pumping, decreases with increase of height. If the height is decreased in order to reduce the pumping costs, the area of the tower for similar performance must be greatly increased. The height of the tower for any given conditions must be determined from the pumping costs, cost of land, and capital and maintenance costs of the tower. There must be a height at which the total of these costs is a minimum. The limiting value is when a cooling pond is used; that is, when the pumping costs are zero and the total cost of cooling is the interest on capital plus the maintenance costs of the pond.

The factors which influence the rate of heat dissipation from a cooling pond are as follows:—Initial temperature of the water entering the pond, atmospheric temperature, relative humidity, wind velocity, solar radiation, earth temperature, and atmospheric pressure. It is unnecessary to take into account the last two of these because their effects are unimportant.

With so many variables the author found it impossible from observations of a cooling tank under working conditions to arrive at any rule for determining the rate of heat dissipation; a small experimental apparatus was therefore constructed. This consisted of a tank 1 ft. × 1 ft. × 6 in.

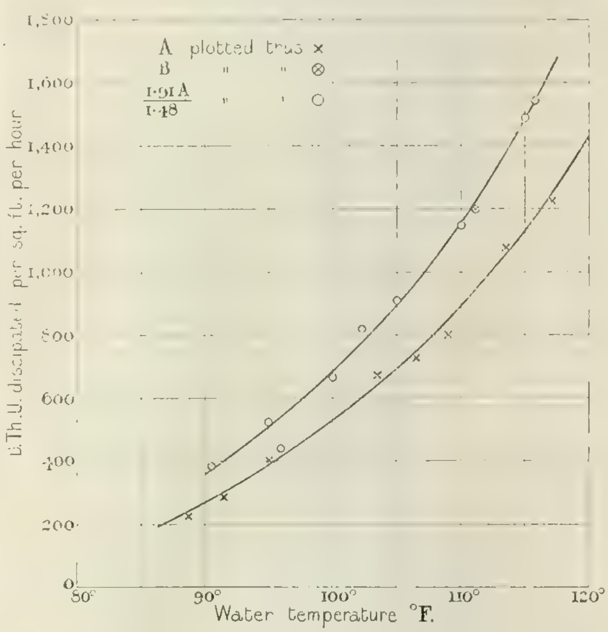


FIG. 5.

	A	B
Wind velocity in ft. per min. ...	750	750.
Relative humidity	83 %	40 %.
Atmospheric temperature	81° F.	96° F.
Water in suspension in 100 lb. of air	1·91 lb.	1·48 lb.

constructed of 1 in. teak, at a convenient distance from which was placed a variable-speed electric fan for the purpose of creating a current of air. The maximum wind velocity produced by this fan was 750 feet per minute measured with a Biram's anemometer.

A number of tests were made in order to determine the rate of cooling under different conditions, each test lasting about four hours. Periodic observations were made of the temperature of the water in the tank, the wet and dry-bulb thermometers, and the wind velocity.

The results obtained from these tests are shown in Figs. 5 and 6. With constant wind velocity and within the range of atmospheric temperature (75° F. to 95° F.) under which the tests were made, the rate of heat dissipation for any given water temperature was found to be approximately inversely proportional to the quantity of

[illegible]

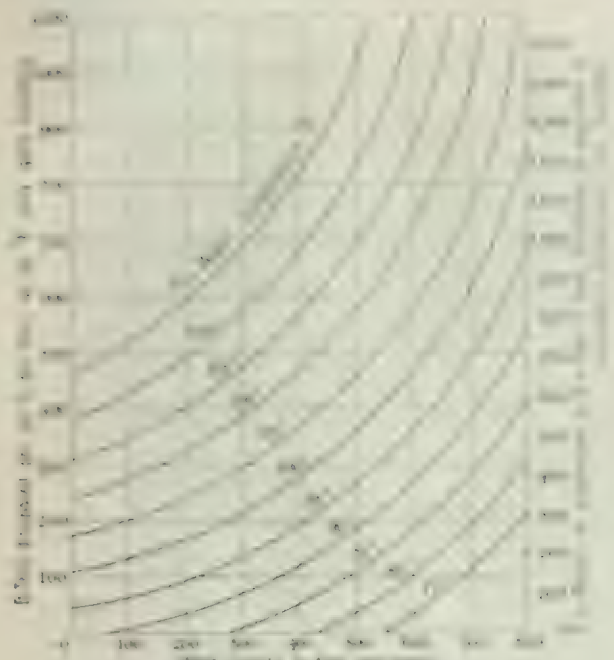


Fig. 6.—Effect of Wind Velocity on Rate of Heat Dissipation in Water-cooling Pond.

Shade temperature 95° F.
[illegible]
[illegible]

The effect of wind velocity is shown in Fig. 6. The [illegible] assuming that the theory holds good that the rate of heat dissipation is inversely proportional to the weight of water in [illegible].

[illegible] the diagram [illegible] is given as the ordinate. The [illegible] By dividing the reading on this scale corresponding to any value of water temperature and wind velocity by the [illegible] of water in suspension in lb., the rate of heat [illegible]

[illegible]

Table [illegible]

[illegible]

	[illegible]	[illegible]		[illegible]	
January ...	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
March ...	[illegible]	[illegible]	273	[illegible]	[illegible]
April ...	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
June ...	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
August ...	[illegible]	[illegible]	[illegible]	357	347
September	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
October ...	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
November	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Average...	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Under the worst conditions, *i.e.* at 78 B.Th.U. per square foot, 6·2 acres are required to dissipate 21,000,000 B.Th.U. [illegible] 22,000,000 B.Th.U. per hour. Under average [illegible] to dissipate 22,000,000 B.Th.U. per hour.

Natural-draught open-type towers and cooling ponds are open to the same objection, namely, that no control of [illegible] rate of heat dissipation.

A well-designed cooling pond must be divided up into a series of compartments through which the water will flow with a gradual and steady reduction of temperature. The compartments may increase in surface area as the temperature becomes lower. A method that might be used is to arrange the compartments so that the same quantity of heat is dissipated from each, per unit of time. The level of the water in the cooling pond should be kept constant so that the dividing pieces come just to the surface but do not project and so interfere with the air circulation.

When it is necessary to combine a cooling with a storage tank it need be of large capacity only at the cold end. The depth of water does not affect the rate of heat dissipation, therefore there is no advantage in having a large quantity of water in the hotter sections. The tank might be constructed so that the depth increases from, say, one foot at the hot end to 10 feet at the cold end.

The most important factor in any cooling apparatus is the temperature at which the discharge water is allowed to leave the condenser. To dissipate 1,000 B.Th.U. in a closed cooling tower with the water at 100° F. double the quantity of air must be provided that is required with the water at 120° F., which means a tower of double the area. In a cooling pond also the rate of heat dissipation at 100° F. is less than half that at 120° F.

mean shade temperature is 75° F. and the mean relative humidity 70 per cent. The steam temperature corresponding to 27½ inches vacuum is 107° F. This temperature is therefore the highest that can possibly be attained in the discharge water, but in practice it will probably not exceed 103° F. Under the conditions of atmospheric temperature and humidity given it is not practicable to cool the water below 85° F. The available temperature difference therefore between the injection-water inlet and outlet is 18 degrees F. If the vacuum efficiency falls, the available temperature difference becomes less, necessitating a larger quantity of circulating water for the condenser and greatly reducing the capacity of the tower to dissipate the heat. If the temperature difference is much less than 18 degress F. the cost of running the auxiliary plant to circulate and cool the water would more than balance the saving due to higher vacuum at the turbine. The capital cost also of the cooling tower would be prohibitive. Under any circumstances therefore the supply of injection water to the condenser should be regulated so as to maintain the highest temperature possible without loss of vacuum, or, as it is more convenient to express it, the highest possible vacuum efficiency.

The data necessary for calculating vacuum efficiency are nearly always available, viz. the value of the vacuum, the barometric pressure, and the temperature of the

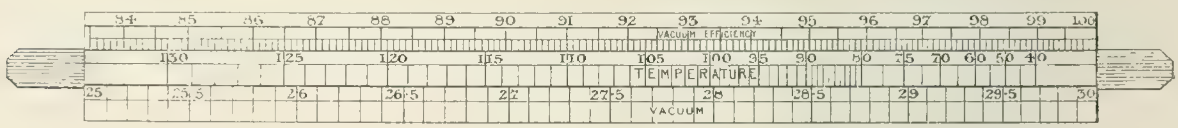


FIG. 7.

In this connection jet condensers have a marked superiority over surface condensers, as they can be constructed to work with a temperature difference of only 2 degrees F. between the injection discharge water and the exhaust steam.

Surface condensers have a greater temperature difference than jet condensers, usually 8 degrees F. Assuming a fixed cooling-tower performance with inlet water at 110° F., and 2 degrees F. temperature difference in the condenser, the vacuum will correspond to 112° F., which at 30 inches barometer is 27·1 inches. The vacuum with 8 degrees F. temperature difference will correspond to 118° F. or 26·6 inches. With fixed cooling-tower performance, therefore, a difference of 6 degrees F. in the condenser discharge water means a loss of 0·5 inch of vacuum, or approximately 2·5 per cent increased steam consumption in the turbines, because if the cooling tower will not dissipate the required quantity of heat with an inlet-water temperature of less than 110° F., then the vacuum at the condenser is bound to fall until this temperature is reached in the injection-water discharge.

The ratio of the actual vacuum on a condenser to the vacuum corresponding to the discharge-water temperature has been termed the vacuum efficiency. In hot and humid countries high vacuum without high vacuum-efficiency is impracticable. For example, suppose it is required to maintain a vacuum of 27½ inches where the

discharge water, but if reference to a curve or table must be made in order to find the vacuum corresponding to every value of the discharge temperature, it is not practicable to take frequent and regular readings. In order to simplify the work of determining this important reading the author devised the calculator which is illustrated in Fig. 7. It consists of a form of slide rule with three logarithmic scales, viz. "vacuum," "discharge temperature," and "vacuum efficiency." The scales A and B are primarily the same and are logarithmic scales of the vacuum from 25 to 30 inches. Scale B, however, is marked off to read the steam temperature corresponding to the vacuum at 30 inches barometer. Scale C reads the quotient of the vacuum readings on scales A and B. Scales A and B are provided with a mark (in the illustration the right-hand end of the scale is used) so arranged that when these are in line the corresponding temperature for any value of the vacuum is obtained. To obtain the vacuum efficiency the corrected reading of the vacuum gauge on scale A is brought into line with the temperature of the discharge water on scale B. The vacuum efficiency can then be read off on scale C opposite the zero mark of the temperature scale. In using the calculator it is necessary that the vacuum readings should be corrected for atmospheric pressure, because of course the steam temperature corresponds to the absolute pressure and not to the reading of the vacuum gauge.

GOOD LIGHTING AND ITS IMMEDIATE EFFECTS FROM THE ECONOMIC STANDPOINT

By V. H. Mackinney and R. Stroud.

[illegible]

INTRODUCTION.

It [illegible] then [illegible]

[illegible] been one of the most powerful means of promoting the [illegible]

[illegible] a matter of importance that the artificial light, which we [illegible] lighting affects the health in many ways. Not only does the general health of people habitually working amid gloomy conditions suffer, but the mere fact of their trying [illegible]

[illegible] were found where as many as 20 or even 30 per cent of the children suffered from defective vision; and much of [illegible] eyes by working in unsatisfactory illumination. During recent years educational authorities have been making [illegible] further improvements.

Good lighting is naturally of special consequence to the young; but the adult worker in the factory also suffers if the light is bad. Any one who has been through a cotton mill and seen the complicated [illegible] realise the strain caused [illegible] light. [illegible]

[illegible] Investigations have shown that the greatest number of mishaps occur in the winter months when artificial [illegible] and engineering workshops, and shipyards, nearly 75 per cent of the accidents have been found to occur during [illegible] artificial lighting which lead to mishaps, and which are therefore remediable.

Then there is also an [illegible] found in the fact that [illegible] consequences.

[illegible] cause of spoiled work, and that it lowers the speed of operators and limits the output. Tests were recently made [illegible] increase in output would more than repay the relatively small cost of putting the lighting on a satisfactory basis.

[illegible] equally to office lighting. A bad[illegible] well kept. [illegible] quences of such a slip may be.

[illegible] lighted restaurant fails to attract custom, a [illegible]

and up-to-date merchants fully recognize the value of well-lighted windows as an advertisement. People naturally crowd to the window where the illumination is exceptionally good. Not long ago some experiments on this point were carried out in a well-known store. The number of people passing who looked into a certain indifferently lighted window was noted. It was found that the window attracted the notice of about 12 per cent of passers-by. Then the services of an expert were called in and the illumination was redesigned in a thoroughly up-to-date decorative manner. The result showed that no less than 72 per cent of the passers-by now looked at the window.

What constitutes "good lighting."—From what has been said above the value of good lighting should be evident. But it is not such any easy matter to say exactly in what good lighting consists. There are, it is true, certain fundamental requirements that must be met. The light should be sufficient. In an office or workshop, for example, we must provide enough light on the work to enable the workman to do his task in comfort, or the clerk to read and write with perfect ease. We must also provide sufficient general illumination in the room for all surrounding details to be clearly visible. Only long experience, however, can show exactly how much light is needed for different classes of work; and only the skill of the trained lighting expert can secure that in any installation this correct amount will be provided. The illumination should be "just right." Too little would be a hindrance to the worker, and therefore uneconomical; too much would be waste.

Another fundamental rule is that the light should be directed where it is needed. This implies two things, that the lights are arranged in the correct positions, and that the lamps are provided with the correct shades or reflectors, screening the light from the eyes of workers and directing the rays just where they are required. Proper shading, in fact, is one of the first requisites in successful illumination. It is not enough merely to provide a bright light. An unshaded source, throwing the light right into the eyes of the worker, instead of on the work he is doing, is a constant source of annoyance; it may even be worse than no light at all. For instance, glaring lights among scaffolding and at the heads of staircases have led men to stumble and have thus actually caused accidents.

There are of course many special points to be considered. The light should come from the right direction, the shadows should be just right, neither too soft nor too hard, the glassware or metal used with the lamps should be suited to the surroundings. All these requirements can, however, be met by the trained illuminating engineer.

From what has just been said in the Introduction it is very evident that a special study must be made if lighting problems are to be undertaken in any other than a haphazard manner. There are various ways of lighting a room, each possibly correct in itself. For instance one might use a direct, semi-indirect, or totally indirect method, but it is quite obvious that the same illumination would not result in each case from the same initial candle-power.

The various sources of light differ in distribution and efficiency, so that it is impossible on the face of it to employ any one type without being acquainted with its properties. The reflection of surroundings also plays an important part in the resultant illumination, and it is quite possible to obtain, due to reflection from the walls and ceiling if the room is within reasonable size and the surroundings light in character, an increase of as much as 80 per cent over the calculated values. The following table indicates the amount of assistance that may be expected from various surroundings:—

Condition of Ceiling	Condition of Walls	Increase over Calculated Illumination
Very dark	Very dark	0 per cent
Medium	Very dark	15 ,,
Medium	Medium	40 ,,
Very light	Very dark	30 ,,
Very light	Medium	55 ,,
Very light	Very light	80 ,,

For the measurement of illumination the term "foot-candle"* is employed. As this is a somewhat unfamiliar term one may ask: How many foot-candles will be required for various classes of service? For this purpose the table on page 831 has been compiled from the researches and opinions of acknowledged authorities.

In order to calculate the foot-candle illumination one must have full particulars as to the polar distribution of the light source which is to be used, also the actual candle-power emitted by the source in the different zones.

In connection with the distribution and candle-power values of bare sources there is at present a controversy as to the correct rating of incandescent lamps. At the present time lamps are marked in volts and watts consumption, with a generally understood efficiency of watts per candle-power; and again it is generally understood that the candle-power is that given out in a horizontal direction. While all lamps had a standard form of filament winding and a more or less standard efficiency, this rating possibly met the case; but now with the advent of different forms of winding and also lamps of different efficiencies, this rating is becoming insufficient.

With half-watt lamps manufacturers do not state the "watts consumption" without qualifying the candle-power, partly to distinguish between lamps of a lesser efficiency and partly to show the lamp in its most favourable light. Here, again, "candle-power" is a loose term. Is it the Hefner unit (which is 0·9 of a British candle-power), horizontal candle-power, candle-power in a downward direction, mean spherical, or mean lower hemispherical candle-power that is meant? This is very important in comparing one source with another, and also in the resultant illumination obtained, and the time now seems to have arrived for a standard rating of lamps. The most ideal method seems to be the rating of lamps in "quantity of light emitted," *i.e.* in lumens, a "lumen" being equal to

* $\text{Foot-candles} = \dfrac{\text{Candle-power}}{(\text{Distance in feet})^2}$.

[illegible]

[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
[illegible]		[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]		[illegible]	[illegible]	[illegible]	
[illegible]		[illegible]	[illegible]	[illegible]	
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Local bench illumination ...	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]		[illegible]	[illegible]	Lobby ...	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	1·5	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
Corridors	0·5	[illegible]	[illegible]	Wharf ...	[illegible]

[illegible]

[illegible]

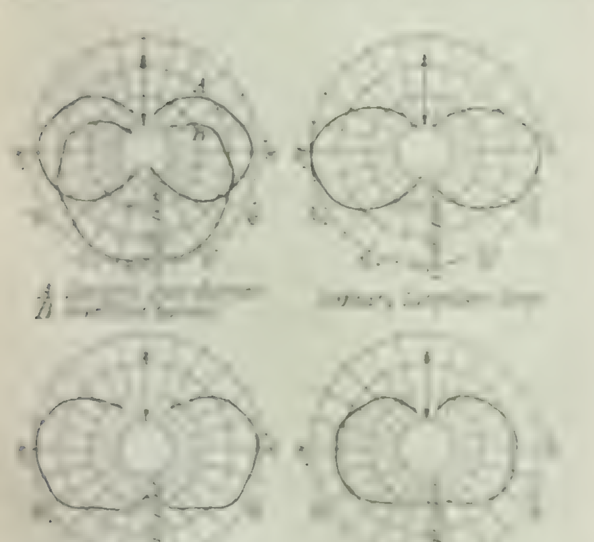


FIG. 1.

measure of the total flux of light. Thus: Mean spherical [illegible] would enable one source to be compared with another.

[illegible]

[illegible] the same over the whole lower hemisphere. In any case [illegible] necessary to use with it a suitable reflector.

[illegible]

[illegible]

(1) [illegible] and the avoidance of glare.

(2) [illegible]

(3) [illegible]

(4) [illegible]

[illegible] is manifest.

[illegible] advantages derived by using [illegible]

[illegible]

4 times the rated horizontal candle-power of the lamp over a zone of 45°, 30°, and 15° respectively from the vertical. Curve 5 shows a still more concentrating prismatic reflector which gives a maximum intensity over a 7° zone of 10 times the rated candle-power of the lamp. These curves show the complete control of the light which it is possible to obtain with properly designed prismatic reflectors and also, from the practical point of view, the flexibility of the system in adapting existing installations with either of the types available to obtain the maximum working efficiency of the light sources.

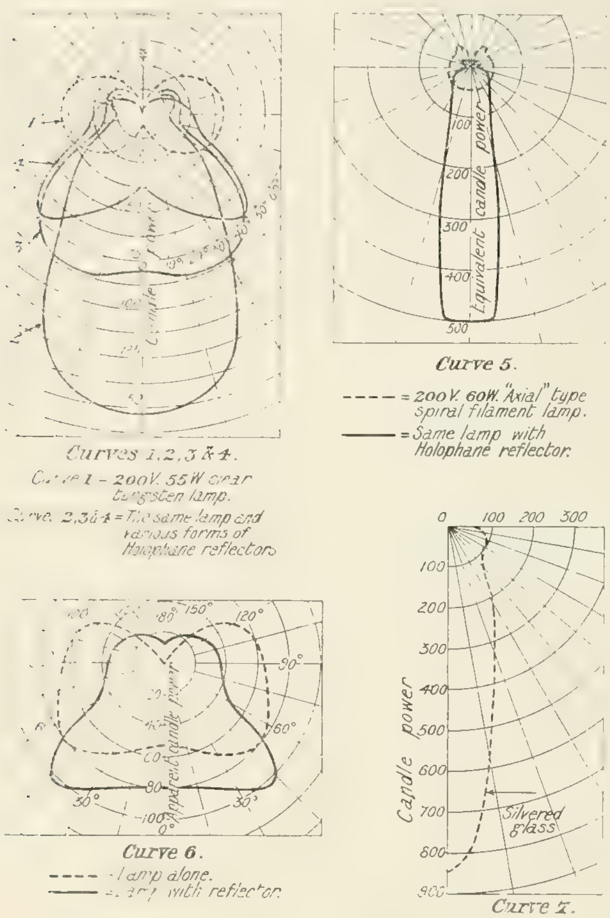


FIG. 2.

Curve 6 shows the distribution obtained from a bowl-type white glass shade, such distribution being of a general nature, and Curve 7 the distribution obtained from a conical fluted mirror reflector, which gives a very concentrating curve. This set of curves of open-type shades and reflectors shows a rather interesting set of conditions: That with white glass one can only obtain a general distribution, with mirrored reflectors only concentrated distribution, and with properly designed prismatic reflectors any distribution from extremely concentrating to extensive. With enclosing glassware a very similar set of conditions exist.

A frosted globe which has only diffracting properties leaves the distribution curve of the illuminant essentially unchanged, and merely smooths it out by averaging the light flux over a narrow range of angles.

An opal or white glass globe, which is an excellent diffuser, entirely changes the distribution curve by substituting the diffusing globe as secondary radiator, and retains only for a small proportion of the light the original distribution.

A lamp in an opal globe (not too dense) is therefore clearly but faintly visible, surrounded by a brightly luminous globe. In the case of the frosted globe the lamp appears as a bright ball of light, while its outline is not visible, the globe being non-luminous or but faintly luminous.

With prismatic globes it is possible to obtain both good diffusion and redirection of the light rays. Clear glass with correctly designed prisms affords a means of controlling light to the greatest extent and redirecting it more efficiently than any other known material.

The following table summarizes on broad lines the properties of the various materials referred to :—

Material	Power for Diffusing	Power for Reflecting	Power for Refracting
Clear prismatic glass	Good	Excellent	Excellent
Opal or white glass	Excellent	Limited	,,
Sand-blasted or acid etched glass	Limited	,,	,,
Mirrored glass	,,	Excellent	,,

Fig. 3 is of interest as showing the extreme extensive

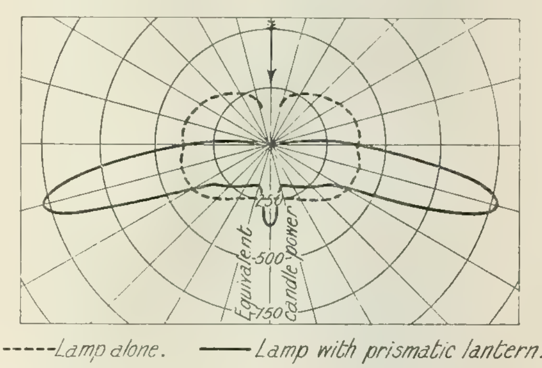


FIG. 3.

distribution which it is possible to obtain with properly designed prismatic glassware. This curve is obtained from an enclosed prismatic globe in conjunction with a 400 c.p. half-watt lamp. The combination has been specially designed for street lighting and gives the maximum candle-power (such maximum being $2\frac{1}{2}$ times the rated candle-power of the lamp) at an angle of 15° from the horizontal, which angle is considered ideal for the purpose. The great advantage of this type of distribution for street lighting is that it is possible to obtain more or less even illumination along the whole street rather than intense light in close proximity to the lamp standards and a great diminution of illumination between them. The particular unit from which this curve was obtained is made up of two pieces of prismatic glassware, one fixed inside the other. The internal piece has a smooth interior

[illegible]

DISCUSSION ON

PAPERS* ON "ELECTRIC COOKING."

WESTERN LOCAL SECTION, [illegible] APRIL, [illegible]

[illegible] Mr. [illegible]: [illegible] apparatus with which it competes. With reference to the [illegible] manufacturers make a great point of an oven retaining its [illegible] depends on the degree of thermal insulation. A certain quantity of heat is required to heat up an oven and raise the meat to the cooking temperature, and then a smaller [illegible] lated thermally is used, very much less heat will be lost, [illegible] time than in a poorly insulated oven. In my opinion Mr. Cooper is quite right in emphasizing the importance of [illegible] preferring to open the oven door (thus immediately [illegible] the use of electric thermometers which would indicate the temperature of the oven on a dial or other apparatus [illegible] viz. the designing of a thermometer that would stand up [illegible]

[illegible] does take place. With a gas oven there must be a draught [illegible] cut off the current if the earth-wire were dis[illegible]

Mr. [illegible]: [illegible] more adequate size of the iron kettle to utilize to the full the heat from the gas ring. In the [illegible] heating by hot-plates, the important point of course is that the surfaces should be planed so as to be in intimate contact. In connection with the comparative cost of heating rooms by gas and electricity, [illegible] elect[illegible] [illegible]

* [illegible]

Mr. Tremain. tests on flexible wires, a great deal of experimenting has been done in connection with telephone work, and it has been found that well-insulated cable of the necessary gauge will stand a great deal of knocking about, the only trouble experienced being at the ends of the wire. I have not given up the hope of finding some satisfactory method of heating water electrically, and suggest that heating engineers might find a solution by using immersion heaters. If this difficulty were overcome, it would be a great advantage both to the consumer and to the supply authority. The use of special coke stoves for heating water does not commend itself to me, as such stoves are very likely to be neglected by servants when hot water is most required. It is remarkable how many hotels and boarding houses fail in this respect when dependent on slow-combustion stoves.

Mr. Kinsey. Mr. A. T. Kinsey: I was pleased to hear that in electric ovens a lamp is always placed in each circuit so as to give an indication that current is in use. In my experience I find that apparatus is frequently damaged by being burnt out when left in the charge of boys, the position of a switch not conveying much meaning to them. When, however, a lamp is placed in circuit, this trouble ceases, and I am glad to know that the insertion of a lamp is now standard practice.

Mr. Proctor. Mr. C. F. Proctor: I am very interested in experiments in connection with the heating of water, and I agree with both the arguments that have been put forward. It would be ridiculous, for example, to try and heat the water in our steam boilers by electricity, but probably it is equally ridiculous from an economic point of view to boil an egg by any but the electrical method. A thermos flask of about 150 cubic centimetres capacity (quite large enough to boil an egg in) would require about 200 watts for 3 minutes to raise the temperature of the water to boiling point and to keep the egg hot until it was thoroughly cooked, the cost being about $\frac{1}{10}$d. and time and trouble being saved. The electrical heating of water is not merely a question of whether it can be done; the time occupied in doing it (or wasted while one is waiting for it to be done) must be also included. For example, a friend has a coil of wire stretched on a few insulators which he puts into a mug of water, switches on the current, and in considerably under a minute the water is hot enough for shaving. As the actual cost of heating the water is considerably under a farthing, to wait even two minutes would represent in the value of the time lost many times the cost of the current actually used. As regards electrical ovens, a great deal of heat is lost by opening the oven door to look at the cooking or for basting the meat. This could be avoided by making the oven open at the bottom; then instead of the whole volume of heated air contained in the oven coming out, only a volume of air equal to the capacity of the joint taken out would be replaced by cold air, which would stay at the bottom of the oven and thus not affect the joint when the latter was replaced. Under present conditions if one wants to cook a small joint, a chicken, or a large joint the same large oven has to be used and heated up, and I suggest that the use of larger or smaller ovens for joints of various sizes would be more economical. In fact the oven that I should like to see introduced would be a bright metal cover of a semi-ellipsoidal construction with the heating elements arranged around the bottom inside edge, and made up in small, easily-dismantled sections. The joint to be cooked would then be placed on a plate and the oven put over it and current switched on. I have heard a suggestion made that the temperature of an oven could be regulated by thermal contacts, which seems a simple solution of the thermometer problem. It is absolutely essential that elements should be quite accessible and easily repaired. In connection with incandescent radiators, I suggest the use of hydrogen instead of a vacuum, thus obtaining four or five times as much heat per element. The use of a thoroughly good heat-insulating material would save a great deal of current, and would very much cheapen the cost of electric cooking. In conclusion I suggest that engineers and manufacturers should go on steadily improving electrical heating apparatus. It is already very good, but far from perfect, and there is plenty of room for improvement.

Mr. Roberts. Mr. D. E. Roberts: While fully appreciating the excellence to which electric cooking apparatus has already been developed, I personally should be inclined to defer the installation of such apparatus for the present, and I think that the opinions that have been expressed appear to favour that view. It undoubtedly takes a considerable time for electric and other apparatus to be evolved and so improved as to be effective and useful in daily life, since there are many difficulties which only experience can overcome.

Mr. Prosser. Mr. F. W. Prosser: The Electricity Department's experience of electric cookers in Bristol does not agree with Mr. Gillott's so far as upkeep is concerned; for whereas Mr. Gillott finds the annual cost of repairs to be about 1s. 2d. per annum per cooker, in Bristol it is 7s. 2d. per cooker for 40 cookers. The upkeep varies considerably and it is difficult to ascertain why one cooker causes much more trouble than another of the same type, but nevertheless it is so. The average annual consumption of energy per cooker is 2,000 units.

Mr. Cooper. Mr. W. R. Cooper: In regard to the retention of heat in ovens, Mr. Walker has disagreed with Mr. Gillott. On this point I wish to support Mr. Walker. Mr. Gillott's view is not correct. Taking the ideal case of an oven with a vacuum all round, this would be most efficient, and yet heat would be retained by that oven for almost an indefinite period. On the other hand, if heat passed through the walls rapidly, the oven would be very inefficient. I should like to emphasize the difficulty of getting truly comparative results with ovens unless the temperature is measured under identical conditions for each oven. As regards the saving by shrinkage when using electricity, I should be glad to have further particulars of the saving effected by Mr. Gillott.

Mr. Chamen. Mr W. A. Chamen: Recently a form of electric cooker was brought into the power station at Treforest which certainly seemed to embody some of the desirable points. It looked something like a small gasometer. I should like to know whether it is not possible to go a step further and get an oven made on the principle of a thermos flask, which seems to me to be nearer the ideal type. I think the suggestion to use various sizes for cooking small joints, chicken, fish, or large joints respectively, is a good one. It seems to involve a great waste of energy to have to heat up a large cooker in order to cook a small joint. In connection with the experience of consumers, an hotel

[illegible]

surface :—

Tight fitting windows ... [illegible]

[illegible]

feet of air [illegible]

[illegible] enough result so long as the shape of [illegible] volume of the latter might be smaller because of its lesser

[illegible]

[illegible] for use [illegible]

Mr. R[illegible] controlling the heat in different portions of the apparatus being mounted on the wall above the oven, so as to enable the cook easily to see what portions of the apparatus are taking current and the degree of heat in each case. I am firmly of opinion that when meat is cooked electrically there is a considerable saving, such saving being greater in comparison with a gas oven than with a coal-fired range, the reason for this being that in the case of the former the moisture in the meat is evaporated and carried away through the flue provided to take off the products of combustion. In the case of a coal-fired oven no such flue is necessary, and consequently the loss is smaller. Practical evidence with regard to the saving of meat when cooked electrically has been obtained at the Bradford Electricity Works, where both an electric oven and a gas oven are installed. The cook is quite at liberty to use whichever he prefers, and as a result of his experience he now invariably does his cooking in the oven heated electrically, as he states that a considerable saving in meat is effected thereby. Greater importance may be attached to this statement when I say that the cook provides and pays for what meat is necessary, and consequently any saving is all to his advantage.

Mr. Gillott. Mr. W. A. GILLOTT (*in reply*): Referring to Mr. Walker's remarks *re* "pioneering," as with almost every class of apparatus we had our difficulties at the commencement, but I am glad to say that we have now overcome the majority of these. My company have recently scrapped a lot of cookers on which they gained their first experience,

Type of Cooker	No. of Cookers	Total Cost of Repairs	Average Cost per Cooker	Details of Failures						Total No. of Failures
				Wiring Faults	Miscellaneous Causes	Hot-plate Elements	Grill Elements	Oven Elements	Terminals	
		£ s. d.	s. d.							
"A"	12	1 15 0	2 11	4	7	—	—	—	—	11
"B"	41	21 17 5	10 8	5	25	42	46	32	—	150
"C"	17	16 19 9	19 4½	2	—	32	—	—	5	39*

* 7 months only.

and have installed a different type of apparatus, which is now giving satisfaction, in upwards of 100 homes in Newcastle district. With reference to the heat-retaining properties of an electric oven, while agreeing in some cases that it is more efficient, one must not forget that we cook more than one class of food for a meal. Sometimes three or four different classes of food are required for one meal, and each may require a different temperature to cook; therefore, an oven that quickly responds in heat to the current applied is preferred. If, on the other hand, one is cooking a class of food that may take a long time to cook, I quite agree that an oven which retains its heat is much better. I consider thermometers to be unnecessary. They do not give the true temperature of the oven, and are not so useful as some engineers make out. Electrical thermometers are too expensive to allow of their adoption for commercial use; they cost approximately £15 each. It is much better to get a lady demonstrator to instruct the consumer how to use the cooker, and it will be found that the consumer will appreciate such a lesson more than a mercurial indication. These periodical visits by the lady cook are very helpful, prevent complaints, and secure success. Mr. Gillott. In Newcastle it is not the gas which we have to compete against so much as coal. Gas costs 2s. 4½d. per 1,000 cubic feet and electricity ¾d. per unit, so that we can show a very satisfactory comparison. Coal, however, costs in normal times 15s. to £1 per ton. The North of England domestic servant is usually brought up in the colliery districts, where the coal fires hold about half a hundredweight of coal. These large fires are always in the kitchen, and are considered necessary to heat the water and kitchen, in addition to cooking.

In reply to Mr. Tremain's remarks, it may be taken that, for cooking, electricity at 1d. per unit costs about the same as gas at 2s. 6d. per 1,000 cubic feet. When the advantages are taken into consideration, however, electricity scores easily. In my own case, I found that when cooking for six persons by electricity, the consumption being 2,129 units per annum, the cost was £6 13s. od. My butcher's bill, however, was £6 10s. od. less per annum than when we cooked by coal for the same number of people. The total cost for the year's working for all heating, cooking, and lighting for a house of this size accommodating four adults and two boys is, I think, quite reasonable. I question very much whether it could be carried out more cheaply under any circumstances. The rateable value is very low; if the house were in a town it would be rated at least at £35.

I agree with Mr. Proctor that a considerable loss of heat occurs each time the oven door is opened. His suggestion of a diving-bell type of oven has been tried. From very careful observations carried out by myself on one of these ovens, I found it could not be conveniently cleaned; moreover, owing to the top being closed (which is the reason of its good heat efficiency) no grease-laden vapour could escape, consequently the vapour condensed and the grease melted when the oven was used again, thereby causing contamination, a very objectionable feature. With regard to his latter remark *re* small joints in large ovens, I have for some time been experimenting with an oven of my own design which consumes energy almost in proportion to the quantity of food cooked; the same oven will cook a small rice pudding at a small consumption or will bake 15 loaves or two 20 lb. joints at a larger consumption.

The type of oven which Mr. Chamen refers to is no doubt similar to the diving-bell type that I have just

[illegible]

quite reasonable.

Mr. W. R. Cooper [illegible] In my opinion ther-mometers should be in an accessible place where they can

[illegible]

construction to avoid this loss [illegible]

[illegible] to [illegible] described.

[illegible]

DISCUSSION ON

"THE POWER SUPPLY OF THE CENTRAL MINING-RAND MINES GROUP."*

YORKSHIRE LOCAL SECTION, 12 MAY, 1915.

Mr. Wright. Mr. H. H. WRIGHT: It is often said that the failings of manufacturers—especially manufacturers of electric plant and switchgear—are particularly due to the fact that their experiences are limited to the actual process of manufacture and do not extend to the working of the machinery and switchgear in practice. I therefore think many of the points raised by the author, and especially the failures described, should be of very great value to manufacturers of plant. There are a few questions that I should like to ask the author. Manufacturers of 3-phase motors often make it a practice to "earth" one of the slip-rings, but I suppose that method would not be allowed in any of the motors installed in the mines under discussion, for the reason that if an earthed slip-ring and an earthed liquid starter are used one of the phases is short-circuited on starting up the motor. I myself do not consider it to be good practice to "earth" one of the slip-rings of an induction motor, and I am not sure whether other troubles do not arise due to that practice, such as circulating earth currents. I should like to know what method is adopted for the protection of the overhead wires against lightning; lightning flashes are very much more severe in South Africa than they are in this country, and I believe the method adopted is very largely that of an earthed guard-wire over the conductors. I should also like to know what type of lightning arrester is adopted. I should think that with the horn type of arrester where a large flash takes place there would be a great risk of breakdown due to surging. Have any failures resulted from dust storms? Also have any of the insulators given way; and if so, have they punctured, or has the trouble been flashing over? I cannot understand why such a large variation of frequency as 5 per cent should be allowed in the supply, and I expect that in actual working the variation is nothing like that amount. On page 629 the author gives a formula for the dimensions of the minimum radial air-gap in millimetres. As far as I have checked it this seems to give a very fair average gap for moderate-speed motors, but in the case of small motors I do not understand the last figure in the formula, namely, minus 0·25, and I should be glad if the author would explain it. On page 617 under Item 4 I should like to hear whether the contactor switches which are used in connection with the slip-ring motors give as gradual and smooth acceleration as the liquid starters. I should like also to see a diagram of connections of the arrangement.

Mr. Burnand. Mr. W. E. BURNAND: The plant described is an exceptionally large one and there is no doubt that metering the supply becomes a different problem from what it is with small consumers. We usually do not need to meter to such great accuracy. I was interested in the method of braking by reverse current on the 3-phase motors; the amount of energy taken or wasted for the purpose of braking is a very large item. Has the author had any experience of introducing continuous current into the primary winding of a 3-phase winding motor? By that means an efficient brake is obtained, and whilst it is perhaps doubtful whether one could brake to as low a speed as with the eddy-current brake described in the paper, I think this should be possible as any normal induction motor will develop full-load torque at less than 5 per cent slip at normal magnetic density, and there is no difficulty in increasing this density with continuous current with a very small expenditure of energy. The advantages as compared with reverse-current braking are that it involves much less strain on the motor, and that excessive voltages, large energy losses, and the use of additional resistances in order to dissipate this energy with reverse-current braking, are all avoided; moreover, the motor runs cooler owing to the iron losses in it being reduced to about one-sixth of the reverse-current value. As compared with the eddy-current brake it has an advantage in avoiding the heavy cost of the latter, and the possibility of trouble due to the introduction of this apparatus, which is not negligible as may be seen by the number of coils, collecting-gear, bearings, and mechanical connections to the winder. It suffers, however, from the same inconvenience as the eddy-current brake in that one cannot brake to zero speed; but even that can be provided at very little additional expenditure of energy, by feeding a very low-frequency alternating current instead of continuous current into the stator. I should like to know whether the author had the opportunity of experimenting in that way, because the cost, amount of energy, and the complications mentioned in the paper would justify a good deal of experimenting with the object of discovering a method of avoiding them. A point occurs on page 628 as to clamping core-plates by bolts, parallel with the shaft, or securing them by circumferential locking keys. I think it is at least debatable whether the latter is the only method. I use both methods and have not found a great deal of difference. Circumferential locking ensures that the plates are arranged parallel at right angles to the shaft, but does not guarantee that they are tight, and I rather favour the use of bolts for tightening the core, but keeping the bolts outside the core plates. One can get them tight in that way, and there is no difficulty in keeping them parallel. Either method gives quite good results, and the only point I want to make is that circumferential locking is not the only method worth consideration. I notice it is mentioned that the bolts pass through the core plates; under those conditions very large currents are liable to be set up in the bolts unless one end is insulated. They form closed circuits and choke back the flux, in addition to causing the bolts to get very hot and wasting energy. On page 629 I notice that carbon brushes are mentioned for the slip-rings. Personally I am not very much in favour of using them on slip-rings. They involve a loss of about 1 volt per slip-ring, and I prefer copper gauze impregnated

* Paper by Mr. J. H. Rider (see pp. 609 and 736).

[illegible] a question of [illegible] neering. It [illegible]

Mr. [illegible] [illegible] stiffness, especially so when such motors are subject to rapid reversals. With regard to the question of soft or loose cores, that is quite inexcusable also, because there has been sufficient experience for 10 years or more to show what a very [illegible] in this country as well as in South Africa. I certainly know of several cases where very large plants have given way owing to the separately attached keys being insufficient in size and insufficiently secured to the circum[illegible] frame; and as a further precaution I have found it better to fill up the radial spaces, if there were any between the punched keys of the plates, and the dovetailed slots with white metal. I think if other people followed the author's example and gave detailed descriptions of their troubles with plant we should very soon come to some [illegible]

Mr. H. A. Neville: [illegible]

[illegible]

Mr. [illegible] First of all [illegible] of joint was used, because I ass[illegible] sizes are used, that is whether they were ta[illegible] the mines and down the shafts. If so, I should be glad [illegible] inside, I fancy that the cables would require to be of very [illegible] is, is the 3-core type still adhered to for even 5 sq. in. cables for comparatively short distances, which will pre[illegible]

Mr. H. E. Yerbury: I am pleased that the author has [illegible] prove useful to members. I feel sure that many engineers have experienced the same troubles as the author in regard [illegible] too fine clearances in alternating-current motors and [illegible] Starting and running resistances are often mounted in such [illegible] of modifying the proposals of the Eng[illegible]

I have always found that an ample margin of copper and close attention to details, even if that means additional cost, have proved a good investment. I should like to ask the author if he has had any experience of rock percussion drills operated by alternating-current motors instead of by compressed air.

Mr. W. H. Brown: I was particularly interested in the illustrations relating to the crushing of rock, as I noticed that there is a very great resemblance between the machinery used in this class of work and in cement manufacture. I refer to such machinery as tube and ball mills, and I should like to ask the author whether the pulp that he mentions as passing to the copper plates is really a damp pulp, or whether it is the dry powder which issues from the tube mills, because, I take it, the ore is quite dry when it goes into the tube mills, and is also dry when it comes out. In trying to visualize the whole process, I do not quite gather at what point the material is wetted, or whether it remains a dry mixture throughout. I notice that demand indicators do not seem to be fitted, and I should like to know whether the author went in for this accessory, because it is one of those things which one can say a great deal about when endeavouring to sell energy, but when purchasing current one would rather the apparatus was not mentioned. In connection with the 3-phase liquid starters, the author mentioned that he saved practically 10 per cent by doing away with these and installing metallic resistances. I gather that at the end of the starting period there was no metal-to-metal contact by which the liquid was actually short-circuited, and I presume that it was owing to this that the 10 per cent of power was lost. Personally I have found that when using liquid starters rated at, say, 300 horse-power, there is a decided "kick" when the liquid is short-circuited, and it is exceedingly difficult so to adjust the liquid that it can be absolutely short-circuited without a relatively large rush of current. Mr. Wright asked a question in connection with the relay starting-device shown on page 617, and I should like to mention that I had a similar case some time ago in which I used this method. The starter was rated at about 60 horse-power, and the cutting out of each section of resistance was dependent upon the current in the preceding section falling to a pre-determined value. On page 629 the author deals with rotor air-gaps, and I should like to ask if he had the smaller machines fitted with adjustable bearings or end-plates in which the air-gap could be adjusted, and whether he used ball bearings or ordinary journals. I was also interested in his remarks regarding temperatures where he says that a temperature of 158° F. is quite high enough to run machines at if a long life is to be obtained. What is the author's idea of a long life? Is it 5, 10, or 20 years?

Mr. R. C. Thackeray: One point which has not been raised is: Who was responsible for purchasing the machinery? I suppose it has been purchased against the specification drawn up by certain consulting engineers. If this is the case the supervision has not been effective, as some of the faults outlined in the paper could not have arisen if inspections had been made during manufacture. The 1 mm. air-gap of the large motor would not be good practice even with a very stiff shaft and ball or roller bearings. The author does not say what type of bearings is in use. Mr. Brown has raised the question of ball bearings and it will be very interesting to know how far these have been made use of and with what success. In the early days of alternating-current motors it was usual to use open slots and large air-gaps, with the result that the machines would carry very heavy overloads for long periods. As alternating-current supply was developed, the motor manufacturers, under keen competition, made a cheaper motor with smaller air-gaps and closed or partially closed slots. These machines are not capable of sustaining heavy overloads, but they are very much cheaper and can compete against foreign machines. As the majority of contracts are given to the lowest tenderer it would not be any use to quote for machines with open slots unless these were specially asked for. Some years ago I heard of troubles which took place in South Africa: they were in connection with large pumping sets. It was found that it was advisable to get a motor which would stand rough handling and that efficiency was a secondary consideration, as it was not possible to get extensive repairs executed in the country at that time. The usual method was to do small repairs and put a new machine in if the damage was extensive. I should expect that on the large scheme described by the author winders and fitters will be on the permanent staff.

Mr. J. A. McLay: My personal interest in the paper has not been so much on the electrical side as on the financial and mechanical sides. The author does not tell us whether the mining companies find this big change from steam to electric driving and operating financially advantageous; and that, after all, is the test of the success of any engineering project. I have known cases where a large amount of capital has been spent in converting from one power system to another, the net result being that the savings effected were just sufficient to cover the standing charges on the capital invested. In those cases the only benefit from the change was got by the manufacturer who supplied the new plant and the power company or department which supplied the new power and presumably made a profit from it. I would not call that successful engineering from the user's point of view, and, as the user's point of view appeals to me much more than the manufacturer's, I wish the author had been able to give us some information on this side. At the same time, as I know something of the lack of economy experienced in mining in this country where steam power is used, I am certain that the mining companies in South Africa found the change not only an enormous benefit from the operating point of view, but also financially. I have no doubt also that the power company found it a profitable arrangement, more especially if the terms of payment are on the same liberal scale as that allowed them for variations in voltage and frequency. We find it difficult at home here to persuade power users to change over from existing steam or other self-contained power systems to the use of electric power from a central supply, and I have no doubt that many of us would like to know how this huge conversion was arranged. Possibly there is not the same innate conservatism in a new country like South Africa as there is here, and possibly the same mistakes have not been made there as have been made here. In any case it seems to me someone deserves great credit for the patience, perseverance, and ability exercised in overcoming all the obstacles and obstructions which must have been raised before this

[illegible] water, that they wear rapidly, but as they have no rubbing [illegible] feeding, hydraulic, mine-unwatering, fire, mine-sinking, [illegible] failure. In fact, it may be taken that in any case where the water to be pumped in gallons per minutes is not less [illegible] possible source of trouble so far as turbine pumps and compressors are concerned, unless great care has been exercised in supplying the particulars of the user's require- [illegible] to run at a minimum speed; with a 50-period supply the designed normal-running speed being for a 4-pole moto- [illegible] matter as the [illegible] may be much more serious [illegible]

[illegible] distance in-bye in a colliery, but though [illegible] country, except on very small overloaded private plants, do not exceed 1½ per cent up and down in the frequency and 3 to 5 per cent in the voltage, and with such [illegible]

[illegible] In the [illegible]

Mr. Rider. plant." I think most undertakings in this country have had trouble owing to their not maintaining a sufficient margin of reserve plant, and many have had to pay dearly for their experience. The author states that a reserve of 25 per cent is not by any means too much. This, however, is a point which in my opinion depends largely on the number of generating sets in the power station; for instance, if four sets of equal size are installed to take the full load, I do not consider another set of the same size as spare—which would represent 25 per cent—to be sufficient. My own ideas on the subject are that, with one set dismantled for repairs, there should still be, even at the time of maximum load, a spare machine capable of immediately taking the place, in case of failure, of any of the sets running.

Mr. Rider. Mr. J. H. Rider (*in reply*): I have been very gratified to find that out of such a comparatively small meeting we have had such an excellent discussion. Following my practice in replying to the discussions at the other Local Sections I will deal with the various points under their subject-matter headings.

Winders.—Mr. Burnand asks if I have had any experience of the use of direct current for braking 3-phase winder motors. I have not. I consider the complication would be too great, and I would rather go in for a Ward Leonard winder at once than use direct current for a 3-phase winder.

Mr. Wright asks whether the contactor switches used in connection with the regulation of 3-phase motors give as gradual and smooth an acceleration as the liquid starter. In practice it has been found that with 9 contactor steps the acceleration curve is quite smooth enough, because it must be remembered that, in addition to the heavy winding drums, there are the cages, the ropes, and the headgear sheaves to move, and these give a certain amount of flywheel effect in starting up, so that the curve is continuous enough for all practical purposes.

Mr. Brown raises the interesting point as to using a metallic short-circuiting device for the rotor when the liquid in the control tank had risen to the top. Such an arrangement would not be practicable, because the short-circuiting switch could not very well be made to depend for its action upon the level of the liquid. It would have to be mechanically connected to the driver's control lever. In starting up a winder the lever is put right over at the start, and the rate of acceleration is determined only by the rate of the rise of the liquid. It would, therefore, not do for the rotor to be short-circuited immediately the control lever was placed over.

Compressors.—Mr. Wilson asks as to the use of direct-driven rotatory air compressors on the Rand as against reciprocating air compressors. The whole of the air supply given by the power company is by means of turbine air compressors, of which some are steam-driven and some electrically-driven. In the few cases where the mines produce their own compressed air, reciprocating compressors are generally used. Full information on this point is given in the paper itself.

Troubles.—Mr. Wright asks for an explanation of my formula for air-gaps. I think his point is that for very small motors the formula would not hold good, as it would apparently give no air-gap at all for certain diameters. This is, of course, correct and the formula is not intended to apply to motors which have rotors under 5 or 6 inches in diameter. Mr. Rider.

Mr. Burnand prefers the use of bolts passing through the core plates rather than circumferential locking keys. We must agree to differ on this point, as personally I think all bolts through the cores are bad, not so much from any magnetic or electrical reason, but because of the difficulty of keeping the nuts tight and the cores parallel. It is unnecessary to insulate bolts which pass through core plates if they are placed outside the active magnetic region.

Mr. Shepherd's suggestion that in building up core plates it is a good precaution to have the radial spaces at the bottom of the slots filled up with white metal is a very proper one, and I suppose the only reason why it is not adopted as standard practice by makers is because of the very small additional expense which would be incurred.

Mr. Shaw asks me to suggest what variations in pressure and frequency I would be satisfied with, and he states that in his case he likes to keep the frequency within half a period up and down. In my opinion a 5 per cent total variation in voltage and a 3 per cent total variation in the frequency should be the limits for any well-organized system of power supply.

I am glad to have the support of Mr. Yerbury in his experience of plant troubles, and particularly with regard to the suggestion of the Engineering Standards Committee referred to on page 629 of the paper.

Mr. Burnand, speaking as a contractor, says that he does not know whether the record of troubles which I gave is going to teach us a great deal in an engineering sense. Well, that all depends on the frame of mind with which we start out to consider the question. They have certainly taught me a great deal, and I think they will teach other people a great deal also, if approached in the right spirit. Mr. Burnand is of the opinion that the troubles are due rather to bad organization than to bad engineering. I do not agree. It is because the designer has little or no experience of plant operation, and particularly of the operation of plants which he himself designs, that most of the troubles start.

Mr. Brown asks whether ball bearings or ordinary journals are used on the motors which have the small air-gaps, and whether the bearings or end plates could be adjusted so as to keep the air-gap constant. We have never used ball bearings, but spherically-seated bearings gave very good results. I do not like the use of arrangements for adjusting the end plates to keep the air-gap regular, but they are standard with certain makers.

Mr. Brown asks what is my idea of a long life for a motor. If a motor will not last for 15 years it is not worth buying.

I gather from Mr. Thackeray's remarks that as the majority of contracts were given to the lowest tenderer it was not much use to quote for specially good machines, and I infer from this that, in his opinion, if the customer is foolish enough to take the lowest offer he is only entitled to get what he pays for and nothing better. I should like to make an observation or two on this point. Why should a purchaser be blamed for taking the lowest offer? He comes into the market and says to a body of presumably respectable contractors, "I want to buy such

and [illegible] place. I [illegible] requirements as clearly as I can, and I ask the manufacturer [illegible] for the [illegible] manufacturing. What is your price?" The contractor draws the price. The purchaser [illegible]. If [illegible] the order is placed, the contractor [illegible] and says "I [illegible] you to pay [illegible] that [illegible], [illegible] a really good machine [illegible]." [illegible] and not the purchaser. If [illegible] the price which should be paid to get a good machine, the purchaser ought to be asked to pay it, but because a contractor wants to get the job and is prepared to cut [illegible] figure to get it, this is no argument why the purchaser should get a good machine.

Mr. [illegible] says that in certain circumstances it is better to [illegible] which [illegible] from those which are higher efficiency. I do not agree, but that is probably because we give different meanings to the word "efficiency." [illegible] to the work [illegible], and [illegible] break down. That is real efficiency [illegible] a breakdown [illegible] would be obtained from a machine [illegible] which requires a [illegible] to electrical energy [illegible].

Mr. Shepherd would like me to [illegible] approximate dimensions of the switch which the Mines have adopted as their standard for the switch house. I regret I have not got the dimensions by me.

[illegible]—Mr. Yerbury asks if I have had any experience of rock percussion drills operated by [illegible] motors. I understand Mr. Yerbury to mean that the movements of the drill would correspond with the [illegible] of the current. I have had no experience [illegible] percussion drills, and [illegible] between [illegible] per minute, the frequency of any ordinary electrical supply would be far too high to get the effect Mr. Yerbury suggests.

[illegible]—The [illegible] Mr. McLeod [illegible] pumps are most interesting, and he certainly points out a [illegible] in the use of such pumps [illegible] circuit in which the frequency can vary between [illegible].

[illegible] Mr. Lang [illegible] in [illegible] gold mines. [illegible] may I be permitted to express my [illegible] the death of the author of the paper referred to, Mr. J. W. [illegible], which took place only a few days after the meeting [illegible] Mr. [illegible] at the meeting. He had been associated with me [illegible] years, and [illegible] should [illegible].

[illegible] with regard to the protection of [illegible] from lightning [illegible]. These are [illegible] points which [illegible] the [illegible] of the power company, which is [illegible] control of the mines. Mr. [illegible] will [illegible] from Mr. [illegible] paper.

Mr. [illegible] with regard to the effect of [illegible] on the copper [illegible], which [illegible] I presume [illegible] and copper [illegible] on the surface [illegible] I cannot give any [illegible] information.

Mr. Brown raises a point which I should have made clear in showing the lantern slides. [illegible] was [illegible] and [illegible] the [illegible] slides [illegible].

In reply to Mr. McLeod and [illegible] to Mr. [illegible], the [illegible] companies [illegible] the change from steam to electric [illegible] in a [illegible] supply to be [illegible]. It was considered that [illegible] would be better [illegible] the Mines [illegible] to [illegible] load.

As to the [illegible] point of the amount of reserve plant [illegible] of [illegible] station [illegible] depends upon the number of generating sets in the station. In my opinion where there are [illegible] per cent. of the total output should be kept as a stand-by.

[illegible]

THE UTILIZATION OF WASTE HEAT FOR THE GENERATION OF ELECTRICAL ENERGY.

By H. HOBSON, B.Sc., Student.

(*Paper read before the* NEWCASTLE STUDENTS' SECTION 25 *January*, 1915.)

The author proposes to divide this paper into two sections—the first dealing with the various forms of waste energy available and the general conditions governing their employment for the purpose of electrical generation, and the second dealing with the considerations involved in the disposal of the power thus generated. For the purposes of this paper it is intended that the term "waste heat" should be interpreted in its broader sense as including both waste steam and waste gases.

There are, roughly speaking, three great sources of waste energy, which are as follows :—

(1) Waste steam, which includes both exhaust steam from non-condensing engines and live steam from boilers supplying engines working intermittently.
(2) Coke-oven gas and waste heat.
(3) Blast-furnace gas and waste heat.

WASTE STEAM.

It is, of course, generally appreciated that the amount of energy to be obtained from steam at low pressures is considerable, but the exceedingly large value of this energy is not always fully realized. It is popularly supposed, even

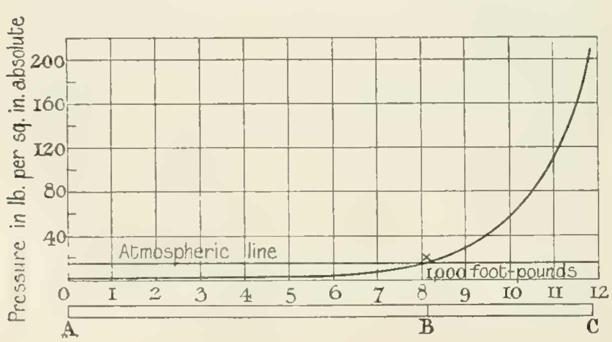


FIG. 1.

among certain engineers, that if saturated steam is expanded from, say, 200 lb. per sq. in. to atmospheric pressure, the major portion of the available energy has been used. In order to bring home the fallacy of such an idea, Fig. 1 has been prepared showing the actual number of foot-pounds of energy contained in one pound of dry saturated steam when expanded adiabatically from any pressure not exceeding 200 lb. per sq. in. (gauge) down to an absolute pressure of $\frac{1}{2}$ lb. or a vacuum of about 29 inches of mercury.

It will be seen that the curve crosses the atmospheric line at the point marked X. Below the curve a diagram has been drawn in block form, showing the actual energy available between 200 lb. gauge and atmospheric pressure (the length B C) and between atmosphere and $\frac{1}{2}$ lb. absolute (the length A B). It will be seen then that, whereas the energy liberated between 200 lb. and atmospheric pressure is 4,000 foot-pounds, that liberated between atmospheric pressure and $\frac{1}{2}$ lb. absolute is 8,000 foot-pounds, or twice as much. The figures given are, of course, theoretical, but if they are multiplied by an efficiency factor the actual energy available can be approximately arrived at, and the proportion will not be greatly altered, the actual ratio in practice being roughly 3 to 2.

At the present time there are a considerable number of non-condensing engines in use, both for colliery winders and for blowing engines at ironworks, from which a supply of exhaust steam may be derived. These are in many instances in good condition, and may continue in use long enough to warrant a generating installation being built in conjunction with them. At the same time it should be remembered that in most cases this form of energy is available only for a limited number of years, the majority of modern steam plants being of the condensing type. In certain cases, such, for instance, as colliery winders, where the engines must of necessity work intermittently, non-condensing engines are, however, still often put down.

It is frequently the case, as in some of the large ironworks of the Tees area, that there is, in addition to a fairly continuous supply of exhaust steam from the blowing engines, an intermittent supply of live steam from the boilers. One station of this kind in the Middlesbrough district contains one 3,000 kw. mixed-pressure turbo set, the turbine being fed with exhaust steam from the blowing engines at about atmospheric pressure. The live steam from the boilers is controlled by a surplus valve so arranged that when the pressure in the steam main rises above a certain limit, live steam is admitted to the turbine in addition to the exhaust steam. After doing work in the high-pressure end, this steam exhausts into the low-pressure end, where it is further expanded together with the exhaust steam from the blowers.

In some of the earlier stations of this type, where the steam had to be piped some distance, it was considered advisable to install a superheater in order to ensure economical transmission. In the case of ironworks where blast-furnace gas was available, this was used for the superheater. Modern development in the protection of steam piping has, however, in many cases rendered it apparent that better results can be obtained by a rather greater outlay on lagging than by the use of a superheater. Often the furnace gas could be used to greater advantage in the production of high-pressure superheated steam, which could be utilized in the high-pressure end of the mixed-pressure turbine.

[illegible]

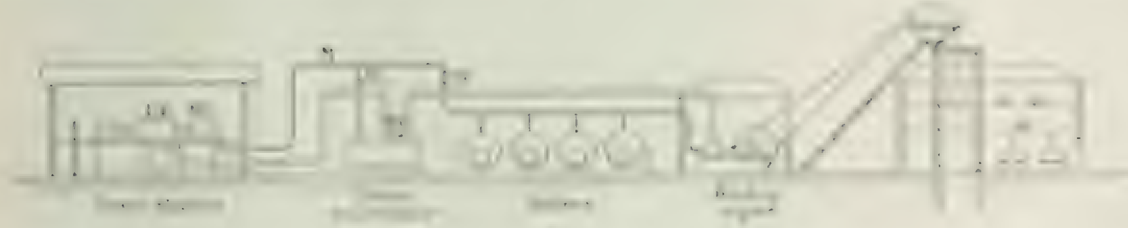


Fig. 2.

[illegible]

[illegible] centred here. This coke was, until comparatively recent years, made in coke ovens of the bee-hive type. In this type of oven about five tons of coal are usually burned at each charge, the [illegible] regulated by an air inlet on the front. All the gas from [illegible] only av[illegible] ment of [illegible] situated close to them, [illegible] k to the use of [illegible] forms, they are always [illegible]

[illegible]

per hour is 2,600 cubic feet, of which 1,300 is available, this amount containing 650,000 B.Th.U.

An ordinary gas engine, if of considerable size, working on the Otto cycle, will take about 13,500 B.Th.U. per kilowatt-hour, assuming an alternator efficiency of 90 per cent or thereabouts. The output, therefore, from 650,000 B.Th.U. is 48 kilowatts.

A new type of high-speed vertical gas engine has recently been brought out by the Fullagar Engine Company. Tests on an engine of this type have given figures as low as 12,000 B.Th.U. per kilowatt-hour, so that the output with such an engine would be 53 kilowatts.

From the above calculations it seems obvious that, apart from other considerations, the gas-engine station should be the most efficient one in conjunction with coke ovens. There are, however, points of importance which militate against the use of these engines. In the first place, the capital cost of gas-engine plant, entailing, as it has, heavy foundation and building costs, has up to the present usually more than balanced the gain in efficiency. Further, in most cases gas engines of large power are as yet rather unreliable as compared with steam turbines, especially when working on a high load factor, and they have no overload capacity.

Considerations such as the above, combined with the difficulty of running low-speed generators in parallel with a large power system, have so far led to the preference of steam turbines in conjunction with coke ovens. But with the advance of gas-engine design, it is probable that engines of this kind will play an important part in future waste-heat schemes.

Blast Furnace Gas and Waste Heat.

In the production of pig iron, the ore is, of course, urned together with limestone and coke in blast-furnaces, and about 22 cwt. of coke is necessary, on the average, per ton of pig iron produced.

Now the weight of gas given off is directly proportional to the weight of coke used, and it is generally assumed to be about six times the weight of the coke. For every ton of pig iron, therefore, approximately $6\frac{1}{2}$ tons of gas are given off. The temperature at which this gas leaves the furnace is about 600° F., and the pressure, which is regulated by a relief valve on top of the furnace, is usually in the neighbourhood of $3\frac{1}{2}$ inches of water. Under these conditions, the volume of gas per ton of pig iron is on the average 150,000 cubic feet, and the calorific value when it leaves the furnace is roughly 55 to 60 B.Th.U. per cubic foot. Of this gas, a small proportion is wasted in the regulation of the pressure, and it is usually necessary to employ a further 30 to 35 per cent in heating the blast. Generally speaking, therefore, there is available for use in driving engines some 60 per cent of the total, or say 90,000 cubic feet of gas per ton of iron.

The gas as it comes from the furnace contains a considerable quantity of dust, and it is essential that practically the whole of this should be removed if the gas is to be used in gas engines. If, however, steam plant is used, it is not usually considered necessary that the gas should be subjected to any cleaning process. It will perhaps be more convenient for the purposes of this paper to consider gas which has been cleaned. This cleaning may be performed by means of some water-spray device in which the gas is intimately mixed with the water, a large proportion of the dust being thus removed, or by some type of dry filter. The gas will in such an apparatus be considerably cooled, its temperature being reduced to about 100° F. The volume will be correspondingly decreased to about one-half, and its calorific value raised to 90 B.Th.U. per cubic foot, some 13 B.Th.U. per cubic foot of hot gas having been lost in the process of cooling through 500° F.

After cleaning, then, we have available for use 45,000 cubic feet of gas of 90 B.Th.U. calorific value, from each ton of pig iron turned out.

Taking a blast furnace dealing with 200 tons of iron in 24 hours, or 8·34 tons per hour, there is from each furnace a yield for outside use of, say, 375,000 cubic feet of gas per hour of a total calorific value of 33,750,000 B.Th.U.

If the blower and furnace auxiliaries, such as hoist, pumps, etc., be of the usual steam-driven type, it is generally found that there is little or no gas remaining for power-station use. In that case, the only available energy for this purpose would be that contained in the exhaust steam from the blowing engine, which might amount to about 500 kilowatts.

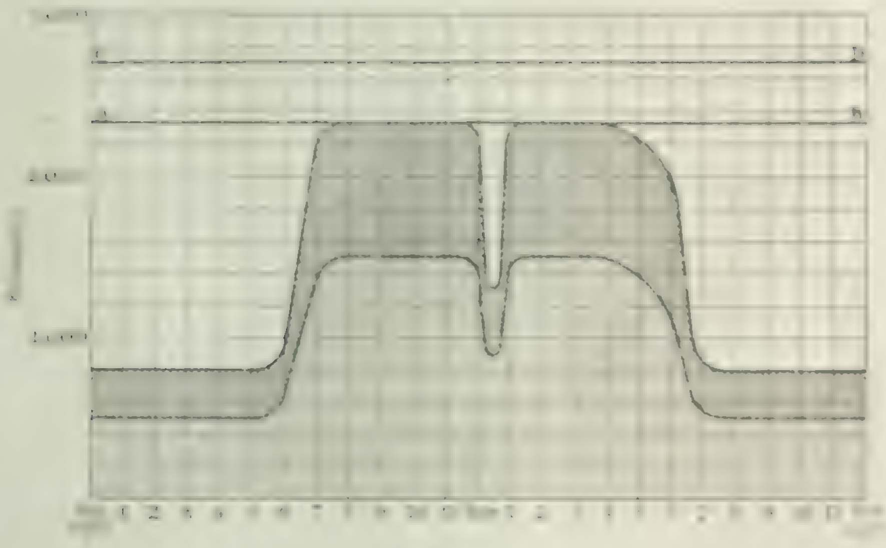
Using gas engines, say, of the Fullagar type, both for the blower and for generating plant, it would be possible to obtain a very fair margin of power. The blower would require from 700 to 1,000 horse-power, depending on the pressure of the blast, so that, say, 9,000,000 B.Th.U. per hour would be thus disposed of. The remaining $24\frac{3}{4}$ million B.Th.U. per hour would be capable of generating roughly 2,000 kilowatts, of which some 200 kilowatts would be sufficient to drive the furnace hoist, pumps, etc. There would then be 1,800 kilowatts available for outside use.

In this case the gas engine presents the only satisfactory solution of the problem, and it is in conjunction with blast furnaces that it has up to now found its greatest field. Many large power installations of this kind have been laid down both in Germany and the United States, and have been in successful operation for some years.

There are, however, certain limitations which must be remembered in connection with the use of this gas. Chief among these is the difficulty of transmission. The pressure at which the gas comes from the furnace being low, and the density being considerably greater than that of coke-oven gas, it is impracticable to transmit the gas more than 200 or 300 feet without using some special apparatus for the purpose. This apparatus may take the form of a compressor at the furnace end of the pipe line, or an exhauster in the power house. In either case, unless the station can be built close to the furnaces, an expensive item is added to the installation. It will be seen, therefore, that the choice of site plays an important part in the success of such a scheme, as if no site is available near the furnaces it may seriously affect the validity of the undertaking.

The question of waste energy has so far been dealt with rather from the mechanical point of view in order to make as clear as possible the various forms of energy available and the methods generally adopted to make use of them. It is now proposed to look at the subject more from the electrical side, and endeavour to determine the main factors governing the employment of the power thus derived.

Consider, for example, the case of a colliery with coke-



plant.

while with the power company as a stand-by, one 2,000 kw.

to above.

units, giving a load factor of 86 per cent.

longer be burned under boilers, but would be converted into coke, which could be sold together with the valuable sulphate and benzole products. The gas could then be utilized in gas engines for generating electricity. The success of such a scheme would doubtless largely depend on the capital expenditure necessary and the sale price of by-products—a very variable and speculative amount—but when it is remembered that coke ovens are being put down at the present time, the sole payment being the by-products for a term of years, it appears that with the advance in the reliability in large gas engines, the idea may in time become practicable.

MODERN POWER-HOUSE CONDENSING PLANT.

By ARTHUR ARNOLD, Student.

(*Abstract of Paper read before the* STUDENTS' SECTION 17 *February*, 1915.)

In the present state of central-station practice with steam-driven prime-movers condensing plant is of great importance for economical operation, and on that account deserves close attention from all who would advance the use of electrical energy. The economy of operation is second only to the saving of capital which is frequently effected by the provision of condensing plant. It is, however, possible to spend too much capital upon condensing gear; the precise figure depends upon the water facilities available and the load factor at which the plant will operate, and such figure may be readily calculated for given circumstances.

With reciprocating engines as prime-movers the size of valve-gear and exhaust passages imposes a limit upon the expansion of the steam, and the ratio of exhaust to initial volume of steam in a cylinder seldom exceeds 15, while in turbine practice it often reaches 150. The wire-drawing effect in the valve passages and the evils of re-evaporation have resulted in the adoption of a vacuum of the order of 25 inches of mercury as a standard for reciprocating plant, but with turbines the lower the pressure the more efficiently the exhaust steam can be utilized, so that the maximum vacuum obtainable is desirable. In practice only some 50 per cent of the improvement which might be expected theoretically is attainable, but even so the $\frac{1}{2}$ in. decrease in back pressure represented by an increase in the vacuum from 29 to $29\frac{1}{2}$ inches (Bar. = 30 inches) gives about 7 to 8 per cent improvement in the steam consumption of turbine plant; whilst an increase from 28 to 29 inches gives some 5 to 6 per cent, and from 27 to 28 inches about 4 per cent improvement. For further consideration of this point reference should be made to the recent paper by Mr. Stoney, read before the Institution of Mechanical Engineers.*

This property of steam turbines has been a large factor in stimulating interest in condenser practice, and high efficiency is now insisted upon.

The function of a condenser is to increase the difference of temperature between the inlet and exhaust of the fluid used in a heat-engine, by lowering the exhaust temperature. Incidentally, of course, this improves the efficiency of the heat-engine. The lowest exhaust temperature is directly dependent, naturally, upon the temperature of the available cooling water, and therefore it is impossible to obtain high vacua and the highest efficiency if only comparatively warm water be used. Neglecting air-leakage, all that would be necessary to obtain, say, a 29 in. vacuum would be a mean circulating-water temperature of about 75° F.—a very usual figure—and furthermore no air pump would be required. With air present, as is inevitable in practice, by Dalton's Law the total pressure in a condenser is equal to the sum of the partial pressures due (1) to the vapour, corresponding to the temperature just as though no air were present, and (2) to the air, as if alone. If the pressure corresponding to the temperature of the condensate be equal to the total pressure, then the partial pressure of the air must be zero and no air pump could remove its infinite volume. Thus for the air to have an appreciable partial pressure, the temperature maintained must be lower than would be necessary were no air present, and the use of air pumps is involved.

The amount of air carried over from the boilers with the steam is of the order of 0·5 to 1·0 lb. per 1,000 lb. of steam, while injection water in jet condensers introduces about $2\frac{1}{2}$ lb. per 1,000 gallons. Aeration of feed water should therefore be guarded against; if the feed be directly heated at atmospheric pressure before injection into the boilers the effect is minimized. Leakages are another cause of the presence of air in a vacuum system. If at any time the air entering a condenser exceeds that which the air pump removes, the condenser gradually becomes "air-logged," and the effect is cumulative until the vacuum drops to a point at which the air is of such greater density that the air pump can remove it as quickly as it enters. Hence the great importance of preventing as far as possible all extraneous leakages. Professor Weighton's "air gauge" provides an effective check upon the air passing through a condenser.

The relation of various commercial types of condensing plant may be shown as below. In practice the choice of the type of plant is frequently narrowed by individual circumstances, and due weight must always be given to the many factors involved.

When a good supply of water suitable for boiler feeding is available a jet condenser may be an excellent proposition. The disadvantage of this class is that the condensate

* G. G. STONEY. The effect of vacuum in steam-turbines. *The Institution of Mechanical Engineers, Proceedings*, p. 741, Parts 3–4, 1914.

[illegible]

[illegible]

[illegible] steam temperature, instead of with the parallel form at a [illegible] pumps fail ; automatic vacuum-breakers should therefore be fitted.

The barometric type is an improvement in many respects. It is an ordinary jet condenser mounted some 36 feet above the hot-well, and since the barometric height [illegible] piping must not, however, be overlooked.

[illegible] type, except the evaporative. The number of gallons per [illegible]

[illegible] quantity pumped.

Several makers have adopted wedged shaped shells, as [illegible] pump dra[illegible] confined to quite a small proportion of the t[illegible] the condenser requiring a minimum surface [illegible] temperature of the condensate is very near the vacuum temperature, [illegible] tions and drained [illegible]

[illegible]

availability of the soft distilled condensate for boiler feeding.

The evaporative is another form of surface condenser. In this type the exhaust flows into stacks of tubes about 4 inches diameter exposed to the atmosphere, and over which a small quantity of water is distributed. Heat units corresponding to the latent heat are taken up from the tubes by that portion of the cooling water which evaporates, and so only a small quantity need be used, and it may be of relatively high temperature. The amount of water circulated is about 10 times that of the steam being condensed, and of this the equivalent of about two-thirds of the condensate is evaporated and must be made-up. The plant is thus particularly suitable for localities with poor or dear water supplies, and further the power demands are quite small, since but little water is circulated and that at a head of only about 10 feet. If cooling towers would be necessary with ordinary surface condensers to furnish say a 28-in. vacuum for a turbine installation, it will be found that the overall mechanical efficiency of a station with evaporative condensers under the same conditions would not suffer if the vacuum were reduced to about 27 inches, whilst a higher hot-well temperature would result. This is because the saving in pumping power would offset the decrease in efficiency of the turbine.

On light loads evaporative condensers are often operated without any circulating water at all, and trouble from leaky joints is quite unusual. On the other hand the plant is relatively expensive in first cost, and in large capacities tends to become unwieldy in size.

Air Pumps.

The many types of air pumps on the market bear testimony to the great deal of thought and ingenuity given to their design. It is realized that the compromise design, at one time rather popular, in which the condensate temperature is sacrificed for the sake of minimizing the size of the air pump is an inefficient expedient, and separate air and water extraction pumps are coming into extensive use.

The question of motor versus steam drive for these and other auxiliaries must be settled by individual circumstances, but with rotary pumps there is much to be gained by collective drive by small auxiliary turbines.

The paper deals with the following forms of air pumps: Reciprocating dry-air pumps with "trick" valve gear; marine type; Edwards type; Weir's "dual" pump; Mirlees-Leblanc "Multijector"; Parson's "augmentor"; the Kinetic air-pump system; the Worthington hydraulic vacuum pump; Rees-Roturbo rotary air pump; the Leblanc air pump; the Wheeler or A.E.G. rotary air pump, and their combined type; and the Jossé-Müller ejector air pump (Willans and Robinson).

Rotary v. reciprocating air pumps.—There can be little doubt that the rotary principle, applied not only to main units but to auxiliaries as well, is an enormous advance. The cardinal features of rotary plant are simplicity and the elimination of the numerous valves and details inseparable from reciprocating motion, thus tending to reliability. The volume of a gas varies inversely as its absolute pressure, so that with large units and high vacua the reciprocating pump must be of cumbersome dimensions; there is then a distinct saving in floor space and capital and a large gain in accessibility with rotary pumps, though many engineers doubt whether the efficiency is much enhanced. With motor-driven reciprocating pumps, either expensive gears must be used or the motor must be of abnormal size and cost to obtain the low speed required; a turbine drive for such pumps is almost impossible. The elimination of clearance losses gives the rotary type another advantage.

Instability is often urged against rotary pumps. While in some of the earlier plants there undoubtedly was trouble from this cause, it has been altogether overcome, and present-day practice shows that no apprehension need be felt upon this score. The term "rotary" is often applied to air pumps which are really water ejectors entraining air, but it would appear that the usage is justifiable, since centrifugal pumps are used without exception to supply the water and the reciprocating principle has been eliminated. There is, however, still considerable room for improvement in the manufacture of rotary pumps. One point of especial importance in power-station work is the reduction of the time which is now necessary with some rotary pumps for the creation of the vacuum.

It is of interest to note that several makers of modern rotary air pumps have obtained on test a higher degree of rarefaction than that corresponding to the vapour tension of the water in use. This can be explained only by surmising that at the very low pressures attained the evaporation from the exposed surface film of the water is sufficient to cool this film materially, and that since the velocity of the water in such pumps is very high, and water itself is such a poor conductor of heat, sufficient time does not elapse for the process of conduction to become appreciable, so that the absolute pressure obtained corresponds to the temperature of the surface film and is lower than that corresponding to the vapour tension of water at the mean temperature of the mass of the water in use.

Tendency of progress.—The tendency of recent practice is towards the elimination of reciprocating pumps, and aims at increased simplicity of parts. Doubtless this tendency will continue, and the future may see even greater progress.

Overall efficiency is being studied more than formerly, and it may well be that individual circumstances will become more important factors in the choice of plant, and not so much the abstract or intrinsic merits of a particular apparatus. A further point which is exerting considerable influence is that with very high vacua and even maximum efficiency in the condensing plant the hot-well temperature will be low enough to cause sweating on economizer tubes.

SOME NOTES ON MODERN METHODS OF ELECTRIC WELDING AND THEIR APPLICATION.

By H. S. Marquand, [illegible]

[illegible]

[illegible] accurately different, and without doubt for certain classes [illegible] expected to replace blacksmith welding; on the contrary, [illegible]

There are two main methods of applying electricity for [illegible] for different classes of work.

[illegible]

(4) [illegible] system, the Slavianoff system, and their variants.

[illegible] those of which he has the most experience.

[illegible] from all the [illegible]

[illegible] weld.

[illegible]

(3) [illegible] from porosity.

(5) T[illegible]

[illegible] and in material.

[illegible]

intervals is made, each in the form of a small circular spot, forming only a small percentage of the total area in contact, the diameter of the spots varying from about $\frac{1}{8}$ inch to $\frac{1}{4}$ inch according to the gauge of the plate. Diagrams B, C, D, and E, Fig. 1, illustrate various methods and types of electrodes for spot welding.

Seam welding.—By this process two sheets of wrought iron or steel are welded together along the edge by a continuous lap weld. The various methods adopted are illustrated in diagrams A, B, C, and D, Fig. 2. The electrodes, it will be seen, consist of two rollers, or one roller and a fixed plate.

Plates varying in thickness from 0·25 mm. to about 3·5 mm. can be quite successfully seam-welded at a rate of about 1 foot per minute, with a consumption of electrical energy of 0·2 to 0·4 unit per foot. The provision of the current required, which varies from about 50 amperes in a small wire welder to about 75,000 amperes in a large tyre welder, is one of the greatest difficulties with which the introduction of electric welding has to contend. The alternating-current transformer, however, provides the manufacturer with an economical means of obtaining a very large current under excellent control.

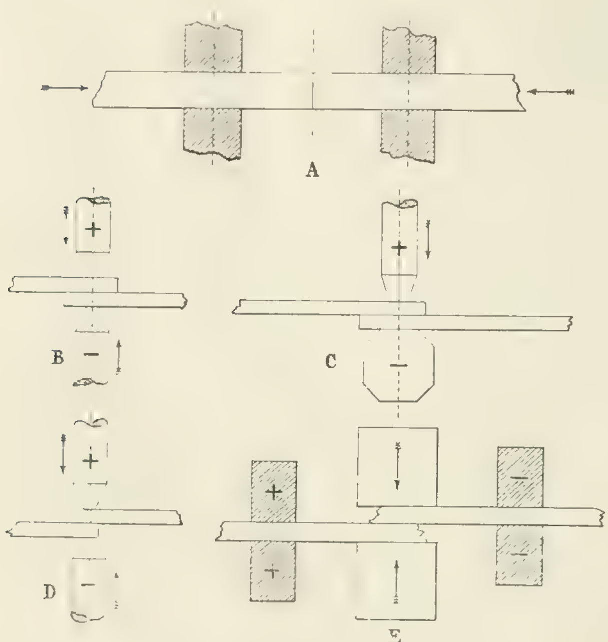


FIG. 1.

Whatever the source of current, the latter is transformed down to a pressure of 2 or 3 volts in a special transformer which, almost without exception, forms part of the welding machine itself. The secondary winding is usually in the form of a copper casting, within which the primary winding and magnet stampings are assembled. The two terminals of the secondary winding are fitted with suitable devices for holding the material to be welded and for transmitting the current, the actual form varying with the design of machine and the class of work for which it is required.

The method of working, whether in butt-welding, spot, or seam welding, is in all cases the same. The parts to be united are gripped in the clamps or placed between the electrodes and brought into contact. This operation may be accomplished in numerous ways according to the type of machine. Generally speaking, however, one of the clamps or electrodes is a fixture, and the other is so mounted that it can be pressed during welding towards the other, either by hand or by some mechanical means.

The switching on of the current can be done either by the operator independently or automatically by the machine, and whatever time may be necessary to bring the material up to a welding heat the current is interrupted as soon as this point is reached. Herein lies one of the great advantages of resistance welding; it never consumes energy unless work is done.

Again, the interruption of the current at the critical instant is also achieved in several ways, either by the operator or automatically by the machine. Immediately the current is cut off, and the production of heat accordingly interrupted, the upsetting or shutting of the weld takes place by continuing or increasing the mechanical pressure first applied to bring the two parts into contact.

The fundamental basis of resistance welding, viz. the use of very large currents, limits its field of application therefore to repetition work, where it reigns supreme by virtue of its simplicity, speed, reliability, and great economy. Fig. 3 shows two curves for the butt-welding of copper. Curve A gives the consumption in kilowatts per weld, while curve B shows the time required in seconds per weld.

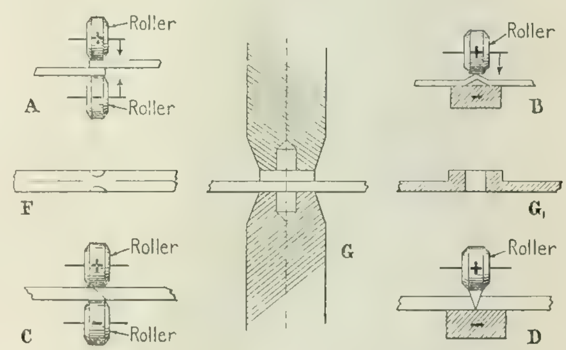
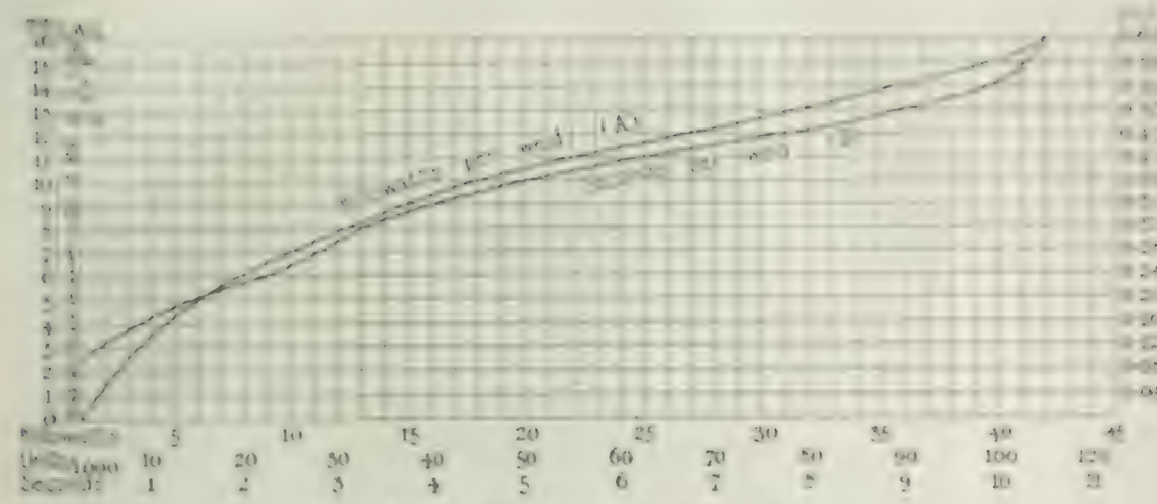


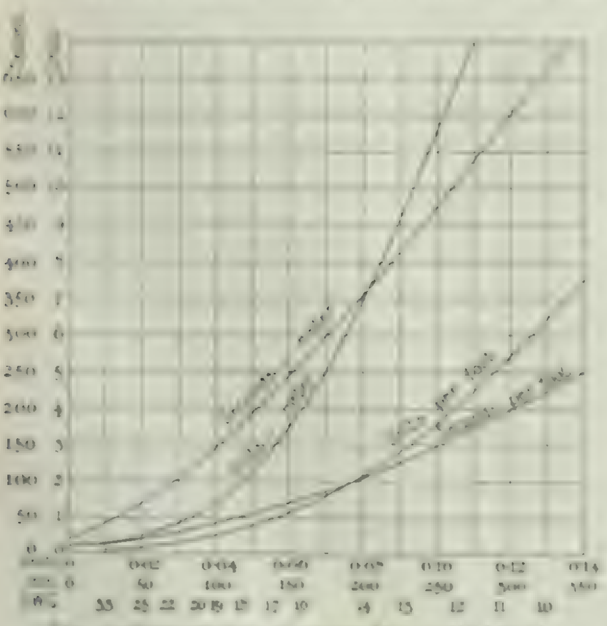
FIG. 2.

Fig. 4 shows similar curves for seam-welding iron, or mild-steel sheets.

A number of precautions are necessary in order to ensure an economical and reliable weld. The metal should be very clean, the clamps must be set tightly on the pieces, and the contact surfaces must be as large as possible. If the contact at the clamps is imperfect the clamps will become very hot.

The distance between the clamps varies with the kind of metal to be welded and with its cross-section. Generally speaking, for iron this distance is twice the diameter of the metal, for brass three to three and a half times the diameter, and for copper four to four and a half times the diameter. Different metals require somewhat different treatment. Steel, pure copper, and similar metals should be handled with care. They must be heated quickly, but if overheated they will lose their structure. Pressure at





anne.led.

what is required is more in the nature of a depositing or

insulated holder, and an arc is struck by bringing
of the carbon pencil in contact with the w
withdrawing it a few inches

and the

system being replaced by a metal electrode, wh

MACHINERY AND APPARATUS.

When it is required to operate several arcs in parallel, the dynamo should preferably be slightly over-compounded so as to give a voltage of about 90 volts; in this case, however, a large resistance is required in series with each arc. When, however, only one arc is to be employed, the machine can with advantage be wound to give approximately the correct working voltage and to have a drooping voltage characteristic. The accessories consist of leads, switches, control apparatus, an insulated holder of light construction, carbon pencils from 6 inches to 12 inches long and ranging from $\frac{3}{8}$ inch to $1\frac{1}{2}$ inches in diameter to suit the work in hand, protective gear for the workman, such as rubber gloves, a hood of stove-pipe or of wood for the head, and screened glasses consisting of a combination of red and green glass which has the advantage of not cutting off too much light while rejecting the harmful ultra-violet rays.

The usual operation with the metal electrode requires continuous current of from 50 to 200 amperes with a voltage drop across the arc of from 25 to 40 volts. A steadying resistance is generally employed in series with the arc. The metal pencil is usually about 3/16 inch thick and is attached to the positive pole of the circuit, the article to be welded being connected to the other pole of the circuit.

APPLICATIONS.

The possible applications of electric-arc welding are far too numerous to be described in detail here, but some of the more important are the repairing of boilers, the welding of fractured cylinders and journal boxes, engine frames, steel castings, broken shafts, etc.

One of the most impressive and most successful applications of the arc-welding process is to be found in the manufacture of steel barrels and casks, and drums of all shapes and sizes. The steel barrel and other companies turn out many hundreds of receptacles every year, all electrically welded, for the storage of the most penetrating and searching liquids, such as benzine, bisulphide of carbon, strong sulphuric acid, petroleum, etc., such vessels being absolutely free from leakage or evaporation. These vessels are capable of withstanding, entirely unsupported, extremely high pressures such as 4,000 lb. per square inch.

The sheet steel is rolled into shape, fixed on the anvil with the loose parts abutting and the joint heated with the arc to a welding heat, new metal being added to thicken the joint. When the desired degree of heat is attained the welder puts aside his carbon, applies the swage shown in Fig. 2 and so toughens the weld.

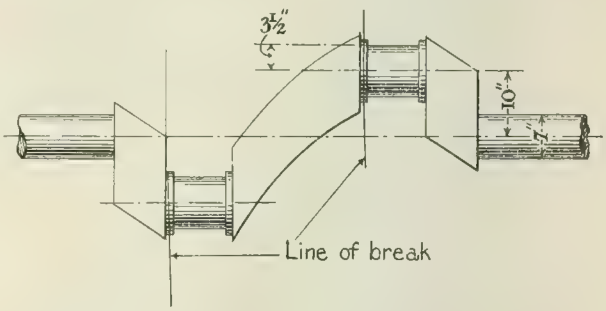
The method of fixing the ends is interesting. The ends are slightly dished, flanged outwards (generally), inserted into the ends of the body, and a band of like material dropped over the outside and inside the flange, flush with the ends.

In preparing work for welding, serious consideration is needed if internal stresses due to contraction are to be avoided. Thus if a fracture in a plate which is tied all round is heated in the immediate vicinity to about 750° F. and the fracture fused or filled in with new metal and allowed to cool off, the recently heated metal will tend to tear apart or remain in tension. Such tension is rarely directed along definite lines, but is irregularly distributed and therefore most liable to result in fracture. Hence, if a fracture in a plate is to be repaired by welding, the plate should be as free as possible to expand, and if it is to be welded into an existing frame or body, the plate should be slightly domed and have a clearance of about $\frac{1}{8}$ inch to 3/16 inch all round.

It is worth noting that the greatest expansion takes place along the grain of the metal.

If the two plates are butted together and a butt strap welded over them, there will be a stress in cooling due to the contraction of the strap forcing the butted ends together. In order to avoid all stress a space should be left between the plates.

These are typical cases, which may be multiplied in practice, but are merely intended to illustrate the author's meaning.



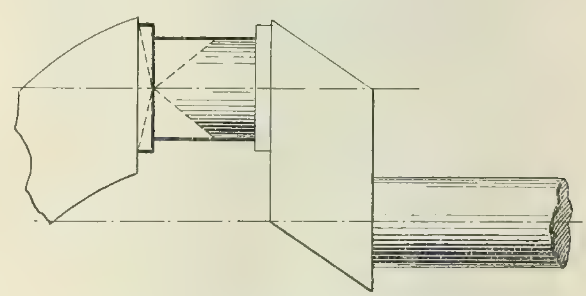


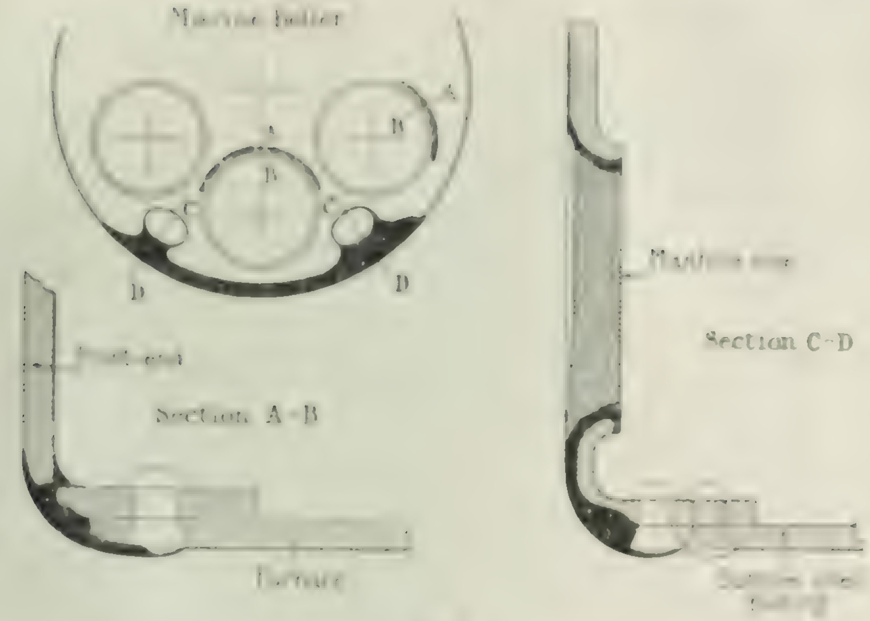
FIG. 5.—Cast-steel Crankshaft Broken off between the Web, repaired by the Electric-arc Welding Process.

Dotted lines represent ends prepared for welding.

This process is widely adopted for welding wrought iron and steel pipes, many complicated arrangements of branch pipes being easily dealt with. Broadly speaking, the same kind of material is used for filling in as in the structure worked upon, but it is preferable to secure material containing certain elements which help to increase the strength or softness of the weld. Metallic pencils of alloys of steel such as manganese steel, nickel steel, vanadium steel, silicon steel, etc., are excellent electrodes for reinforcing certain welds.

In general the process of preparing the fractures or joints for welding is the same in all cases, namely in preparing a cavity large enough to allow for working the metal before starting to weld.

Cracks in plating or structures must first be chipped out to the solid metal with a chisel, or burned out with the graphite electrode, and a V-groove formed, which is filled


A
B
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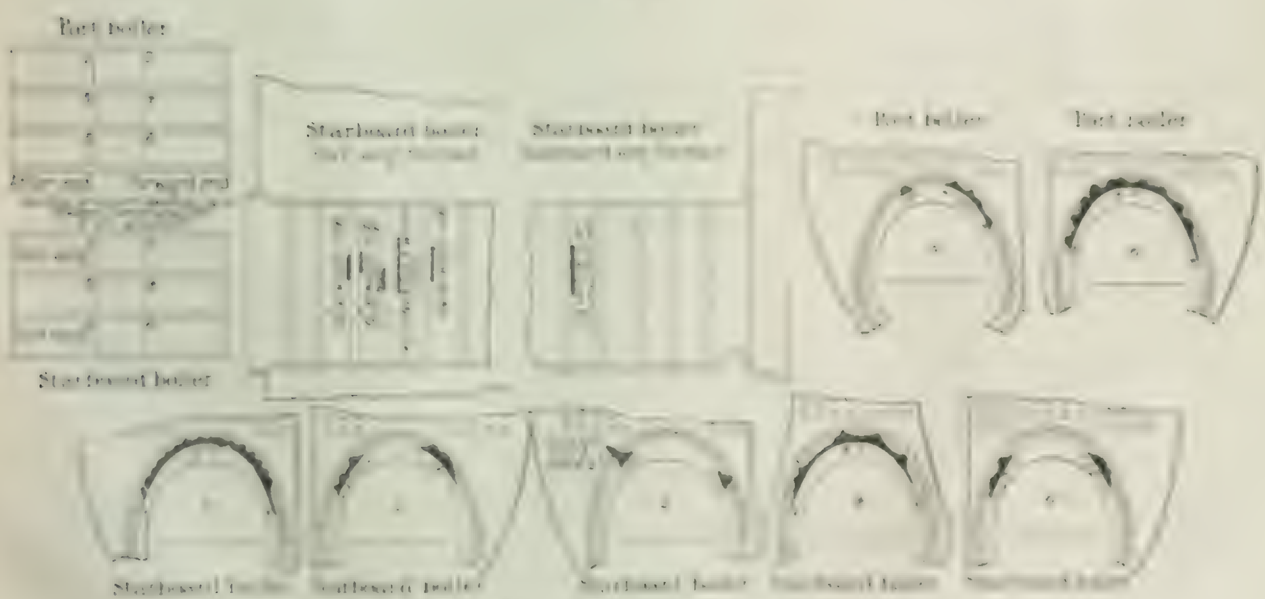
Section A-B
Section C-D



the author's company, which were carried out to the satisfaction of the surveyors of the Board of Trade, Lloyd's Register, and the various Classification and Boiler Insurance Societies, this being the best guarantee of their reliability and efficiency.

TABLE 1.

Chemical Analyses.

	Electrically Welded		Acetylene Welded	
	Unwelded Metal	Welded Joint	Unwelded Metal	Welded Joint
	Per cent	Per cent	Per cent	Per cent
Silicon	0·009	0·003	0·009	0·002
Carbon	0·15	Trace	0·15	Trace
Sulphur	0·025	0·020	0·085	0·071
Phosphorus ...	0·068	0·043	0·068	0·067
Manganese ...	0·64	0·27	0·49	0·34
Iron (by difference)	99·108	99·664	99·198	99·520
	100·000	100·000	100·000	100·000

TABLE 2.

Mechanical Tests on Electrically-welded Steel Plates with a Nominal Strength of 56,000 *lb. per sq. in.*

Plate Thicknesses	Elastic Limit. Lb. per sq. in.	Tensile Strength. Lb. per sq. in.	Elongation. Per cent in 8 in.	Efficiency. Per cent
$\frac{1}{4}$ in.	40,930	54,650	0·45	97·6
$\frac{3}{8}$ in.	44,930	53,020	5·75	94·7
$\frac{1}{2}$ in.	40,160	51,280	4·75	91·6

NOTE.—The elongation in the welded material was less, of course, than in the original stock because it is less fibrous, but its ductility could be improved by hammering after welding, and this is frequently done with heavy sections like side frames, steel castings, etc.

Fig. 6 illustrates repairs effected to the main boilers of a large cargo vessel. The fractures extending circumferentially in the radius flange of the front ends of the boilers were cut out to the full section of the plating, veed out and welded up as shown, partly from the water-side and partly from the outside. The landings were then built out and extended over the fractures so as to strengthen the whole flange. Also the wasted and defective plating of and in the way of the manholes was built up solid as shown and the doors refitted.

Fig. 7 illustrates repairs effected to the main boilers of a large passenger liner.

When using the metallic system it is very necessary to begin at the bottom and hammer up the metal as the work proceeds. With this system welds can be made to stand from 22 to 38 tons per square inch with elongations of 15 to 25 per cent and elastic limits of 12 to 30 tons per square inch.

Tables 1 and 2 show the effects of welding upon the metal, tests on oxyacetylene-welded samples being included to facilitate comparison. For these analyses drillings were obtained from the welded joints. The plates were tested mechanically both longitudinally and transversely along the welded joints, and for comparison along the unwelded metal. The results of the mechanical tests of the unwelded metal are the mean values of three samples. The chemical analysis and also the mechanical tests were specially made by Mr. F. C. Tipler, Chief Chemist in the locomotive department of the London and North-Western Railway at Crewe.

TABLE 3.

Mechanical Tests on Riveted, Arc-welded, and Acetylene-welded Joints.

	Breaking Strain	Length after Breaking	Efficiency
	Lb.	In.	Per cent
Original piece of steel plate	58,600	8·80	97·66
Lap joint, electric arc-welded	54,800	8·94	91·33
Lap joint, riveted and welded	54,200	9·22	90·33
Butt joint, electric arc-welded	47,800	8·28	97·66
Butt joint, acetylene-welded	36,800	8·23	61·33
Lap joint, riveted only ...	35,000	—	58·33

The nominal strength of the steel plates was 60,000 lb. per square inch.

In order to test the relative values of riveted, electric arc-welded, and acetylene-welded joints, a set of samples was made up and tested, with the results shown in Table 3. The pieces of steel plate were all $\frac{3}{8}$ inch thick and 8 inches long in the straight section. By reinforcing at the weld practically any efficiency can be obtained.

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(FOURTH LIST.)

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[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
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Clarke, J.	[illegible]	[illegible]
[illegible]	[illegible]	Major
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[illegible] J. N. C.	[illegible]	Major
[illegible]	[illegible]	[illegible]
Leaf, E. H.	[illegible]	[illegible]
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[illegible]	[illegible]	Major
Pringle, J. S.	[illegible]	2nd Lieut.
Robins, F. J.	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

Associate Members.

Name.	Corps, etc.	Rank.
[illegible]	[illegible]	2nd Lieut.
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	2nd Lieut.
[illegible] H. L.	[illegible]	[illegible]
[illegible]	[illegible]	2nd Lieut.
[illegible]	[illegible] Sappers and Miners, Indian Army	2nd Lieut.
[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	2nd Lieut.
[illegible] C. A.	[illegible]	[illegible]
[illegible]	3rd Manchester Regt.	2nd Lieut.
[illegible] M. A.	[illegible]	[illegible]
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[illegible]	Royal Field Artillery	2nd Lieut.
[illegible]	[illegible]	[illegible]
Clears, P. J.	[illegible]	[illegible]
Coghlan, J.	[illegible]	[illegible]
Cowan, S. H.	[illegible]	[illegible]
Cresswell, F. G.	[illegible]	[illegible]

Associate Members—continued.

Name.	Corps, etc.	Rank.
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	2nd Lieut.
[illegible]	[illegible]	2nd Lieut.
Edwards, E. A.	[illegible]	2nd Lieut.
[illegible]	[illegible]	[illegible]
Eriksson, C. F.	[illegible]	[illegible]
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Gardner, M. R.	[illegible]	[illegible]
Gellion, F. J.	[illegible]	[illegible]
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Harper, E. J.	[illegible]	[illegible]
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Henry, J. R.	[illegible]	[illegible]
Henry, W. J.	[illegible]	[illegible]
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McArthur, R. T.	[illegible]	[illegible]
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[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
Mitchell, W. J.	[illegible]	[illegible]
[illegible]	[illegible]	2nd Lieut.

[illegible]

ASSOCIATE MEMBERS—*continued.*

Name.	*Corps, etc.*	*Rank.*
Newman, A. R.	Royal Navy	Engine Room Artificer
Nichol, J. O.	R.N.V.R.	Lieutenant
Noyce, C. H.	Divisional Engineers, R.N.D.	
Ogilvie, H.	4th Battalion, Canadian Force	Private
Paton, G.	9th Border Regt.	2nd Lieut.
Payne, F. G.	10th Lincolnshire Regt.	Lieutenant
Payne, J. V.	Army Service Corps	Driver
Podmore, A.	Royal Engineers	2nd Lieut.
Pontet, B.	Bihar Light Horse (Reserve)	Trooper
Porter, A. R. Z.	Queen's Westminster Rifles	Lieutenant
Porter, T Y.	East Lancashire A.S.C.	2nd Lieut.
Potts, T. F.	Royal Engineers	Staff Sergeant
Prendergast, H. H. L.	Railway Transport Dept.	2nd Lieut.
Preston, E. B. C.	32nd Sikh Pioneers	2nd Lieut.
Price, A. R. P.	Reserve of Officers, Indian Army	2nd Lieut.
Prichard, W. C. H.	Royal Engineers	Captain
Restler, J. D. K.	Royal Naval Division	Sub-Lieut.
Roberts, G. B.	Royal Engineers	Major
Robertson, A. M.	Renfrewshire (Fortress) R.E.	2nd Lieut.
Robinson, E. G.	Royal Navy	Commander
Seeley, C. G.	Inns of Court, O.T.C.	Trooper
Simpson, R. C.	39th Infantry, Australian Militia	Lieut.-Col.
Slack, D. H.	Kent (Fortress) R.E.	2nd Lieut.
Smith, Prof. C. A. M.	Hong-Kong Volunteer Reserves	Corporal
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Stewart, W. D.	London Scottish	Lance-Corpl.
Strafford, C.	Hong-Kong Volunteer Reserves	Private
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Tilley, F. E.	Divisional Engineers, R.N.D.	Sapper
Trevett, C. G.	South African Engineer Corps	Lieutenant
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Turpin, A. E.	Royal Field Artillery	2nd Lieut.
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Webb, P. D.	Calcutta Scottish Volunteers	Private
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Wightwick, H. G.	Singapore Volunteer Infantry	2nd Lieut.
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Williams, R. A.	Royal Engineers	2nd Lieut.
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Maunsell, M. C.	Reserve of Officers	Major
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Day, I.	Hong-Kong Volunteer Reserves	Sapper
Feloy, J. P.	Royal Garrison Artillery	Lieutenant
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Monks, C. E.	10th North Staffordshire Regt.	2nd Lieut.
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Wyatt, E.	Divisional Engineers, R.N.D.	
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STUDENTS.

Name.	*Corps, etc.*	*Rank.*
Aspland, G. D.	West Riding Divisional R.E.	Lieutenant
Baker, H. G.	Divisional Engineers, R.N.D.	Sapper
Begg-Robertson, E. D.	8th Essex Regt.	
Bishop, B. L.	Royal Anglesey R.E.	2nd Lieut.
Booker, H.	Divisional Engineers, R.N.D.	
Bower, H. A.	Royal Naval Air Service	Flight Sub.-Lieut.
Carter, F.	Yorkshire Hussars Yeomanry	Trooper
Clark, R. M.	Divisional Engineers, R.N.D.	Sergeant
Clarke, C. V.	11th Devonshire Regt.	2nd Lieut.
Clarke, R. St. J.	6th Hawaki Co., New Zealand Force	Private
Clayton, B. C.	Royal Naval Air Service	Flight Sub-Lieut.
Dawnay, C.	6th Yorkshire Regt.	
de Grandpré, I. G. D.	French Army	Corporal
Duckworth, F. F.	Hong-Kong Volunteers	Gunner
Dunn, R. C.	New Zealand Expeditionary Force	
Eaddy, C. T.	19th Royal Fusiliers	Lance-Corpl.
Fiske, A. R.	20th County of London Regt.	
Foote, N. V.	2nd Australian Light Horse	Trumpeter

Name.	Unit, &c.	Rank.	Name.	Unit, &c.	Rank.
[illegible]	[illegible] Light Infantry	2nd Lieut.	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]		[illegible]	[illegible]	[illegible]
Hall, T. H.	[illegible]	2nd Lieut.	[illegible]	Royal Engineers	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	Corporal	[illegible]	[illegible]	[illegible]
[illegible]	Royal Field Artillery	2nd Lieut.	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]	Royal Field Artillery	2nd Lieut.	[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	Voss, H. A.	[illegible]	[illegible]
[illegible]	Royal Field Artillery	2nd Lieut.	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	Royal Engineers	[illegible]	[illegible]	[illegible]	
Fallot, A. C.	[illegible]	2nd Lieut.	[illegible]	[illegible]	

INSTITUTION ANNOUNCEMENTS

ASSOCIATE MEMBERSHIP EXAMINATION, APRIL, 191[illegible]

Examiners:

English Essay	C. C. [illegible], M.A.
Translation from French	H. Borns, Ph.D.
Applied Mechanics / *Heat*	Prof. [illegible]
Chemistry	Prof. [illegible]
Electricity / *Electric Lighting and Power*	P. V. Hunter.
[illegible]	[illegible], M.A., D.Sc.
[illegible]	Prof. [illegible], M.A.

Pass List.

[illegible]
Hatch, William Ashton.
[illegible]
[illegible]
[illegible]

THE INSTITUTION ELECTRICAL MUSEUM

[illegible] the Institution to secure in the Institution building the [illegible]

[illegible]

[illegible]

EMPLOYMENT OF DISABLED SAILORS AND SOLDIERS.

The Council desire to call the attention of members to the demand for employment from disabled sailors and soldiers. The number at present requiring employment is not very large, but it may increase considerably during the next few months.

The Committee which deals with the question of the employment of these men is The Association for the Employment of Ex-Soldiers, 119, Victoria-street, Westminster, London, S.W., to whom all applications for further information and lists of the local branches of the Association should be addressed. Many of the men could no doubt after some training do useful work as switchboard attendants.

Attention is also drawn to the Report of the Local Government Board Committee upon the provision of employment for sailors and soldiers disabled in the war, copies of which can be obtained from any bookseller, at the price of 1½d. each.

COPY OF LETTER FROM THE POLICE DEPARTMENT AT WELLINGTON, NEW ZEALAND.

The following letter has been received by Mr. J. Orchiston, Local Honorary Secretary and Treasurer of the Institution for New Zealand:

Police Department,
Wellington.
6 May, 1915

Sir,

With reference to your letter of the 8th December last and subsequent correspondence, relative to the letters A.M.I.E.E. being used by ——, of ——, without his being entitled to do so, I beg to inform you that —— was convicted of this offence on the 3rd instant and fined £5 and costs.

The two copies of the List of Members of the Institution of Electrical Engineers supplied by you are returned herewith.

I have the honour to be, Sir,
Your obedient servant,
(Signed) M. Ellison,
Supt. for Commissioner of Police.

J. Orchiston, Esq.,
Chief Engineer of Telegraphs,
Wellington.

ACCESSIONS TO THE REFERENCE LIBRARY.

Baillie, T. C. Electrical engineering. vol. 1, Introductory. 8vo. 244 pp. *Cambridge*, 1915

Blondel, A. Calcul des lignes aériennes au point de vue mécanique par des abaques. [Éditions de "La Lumière Electrique"]. 4to. 63 pp. *Paris* [1915]

Canada. Dept. of Mines. Mines Branch. Annual report on the mineral production of Canada during 1913. [By] J. McLeish. 8vo. 363 pp. *Ottawa*, 1914

Researches on cobalt and cobalt alloys, conducted at Queen's University, Kingston, Ontario. pt. 2, The physical properties of the metal cobalt. By H. T. Kalmus and C. Harper. 8vo. 58 pp. *Ottawa*, 1914

Creagh-Osborne, F. The magnetic compass on land. sm. 8vo. 15 pp. *London*, 1915

Croft, T. Wiring of finished buildings. A practical treatise, dealing with the commercial and the technical phases of the subject, etc. 8vo. 286 pp. *New York*, 1915

Engineering Standards Committee. [Publications]. no. 12, 70. [no. 12, revised]. fol. *London*, 1915

12, British standard specification for Portland cement.

70, Report on British standard pneumatic tyre rims for automobiles, motor cycles and cycles.

Fieldner, A. C., *and others*. Analyses of mine and car samples of coal collected in the fiscal years 1911 to 1913. [U.S., Dept. of the Interior, Bureau of Mines, Bulletin 85]. 8vo. 454 pp. *Washington*, 1914

Fréchette, H. Report on the non-metallic minerals used in the Canadian manufacturing industries. [Canada, Department of Mines, Mines Branch]. 8vo. 207 pp. *Ottawa*, 1914

Gaster, L., and Dow, J. S. Modern illuminants and illuminating engineering. 8vo. 476 pp. *London*, 1915

Gillett, H. W. Brass-furnace practice. [U.S., Dept. of the Interior, Bureau of Mines, Bulletin 73]. 8vo. 302 pp. *Washington*, 1914

Haanel, B. F. Peat, lignite, and coal. Their value as fuels for the production of gas and power in the by-product recovery producer. [Canada, Dept. of Mines Mines Branch]. 8vo. 276 pp. *Ottawa*, 1914.

Home Office. Report on battery-bell signalling systems as regards the danger of ignition of firedamp-air mixtures by the break-flash at the signal-wires. By R. V. Wheeler. fol. 13 pp. *London*, 1915

Johnson, G. Electric lighting accounts. ["The Accountants' Library," vol. 29]. 2nd ed. 8vo. 188 pp. *London*, 1913

PROCEEDINGS OF THE INSTITUTION.

[illegible] GENERAL MEETING [illegible] MAY, 1915.

Proceedings of the 43rd Annual General Meeting of The Institution of Electrical Engineers, held on Thursday, 27 May, 1915—Sir JOHN SNELL, President, in the chair.

The minutes of the Ordinary Meeting held on [illegible] April, 1915, were taken as read and confirmed.

The President reported the result of the ballot for the election of new Members of Council (see page [illegible]).

The PRESIDENT: I should like to make a few comments with regard to the election of new Members of Council. Out of over [illegible] ballot papers that were issued to the members of the Institution only [illegible], or slightly more than one-eighth, were returned. I think it is to be regretted that the Council as now constituted is not more representative of the whole of the electrical industry than the names would suggest. There has been a tendency during the last year or two for the Members of Council to [illegible] rather towards the lighting and power section of the profession to the exclusion of members representing the great telegraphic and telephone interests and the manufacturing interests. Although it is too late to make any alteration this year, I venture to hope, both as President and also in my capacity as a Member of the Committee, that another year it will be found possible to devise some means of electing a Council which will be more truly representative of every branch of our profession.

The list of candidates for election and transfer approved by the Council for ballot was taken as read and was ordered to be suspended in the Hall.

Messrs. [illegible] and [illegible] were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the result of the ballot was declared as follows:—

ELECTIONS.

[illegible]

TRANSFERS.

[illegible]

The following donations were announced as having been received, and the thanks of the meeting were accorded to the donors :—

Benevolent Fund: Messrs. Dick Kerr & Company, Ltd., F. B. O. Hawes, P. H. Brown, H. L. Leach, N. Prentice, H. F. Proctor, J. B. Smith, and Sir John Snell.

Library: The Engineering Standards Committee, W. Kingsland, C. O. Mailloux, D.Sc., Marconi's Wireless Telegraph Company, Ltd., and A. A. C. Swinton.

The PRESIDENT : It now devolves upon me to present the Annual Report of the Council. The Report has been already circulated to the members (see page 722), and I therefore do not propose to read the whole of it, but I desire to draw attention to a few of its more salient points. During the year a great deal of work has been done by the Institution in connection with national service. Not only has the Institution put offices at the disposal of the War Office, but the President at that time, Mr. W. Duddell, F.R.S., and Mr. A. P. Trotter, Major-General R. M. Ruck, C.B., Mr. R. Hammond, and one or two other members, were instrumental in recruiting an Engineer Unit for the Royal Naval Division. Very excellent work was done by those members, so much so that there is no doubt that the type of man selected gave the necessary confidence to the War Office to call upon the President to make selections for commissions in the Royal Garrison Artillery and in a few instances in the Royal Engineers, as well as Inspectors of Works in France, with Hon. Lieutenancies, R.E. A great deal of work has fallen to my share during the months from October to April, and even occasionally now, in interviewing candidates and recommending certain of them for commissions, and I am happy to say that not one of the recommendations of the Institution has been "turned down." All these gentlemen were recommended as subalterns, but I am glad to say that in a few instances they have already attained captain's rank or that of first lieutenant. The number of members on naval or military service now totals 928, and seeing that the total membership of the Institution is under 7,000, and that many of our members are also engaged on other national work, such as the manufacture of munitions of war, I think the above proportion is a very fair percentage and speaks very well for the patriotism of our members. We have also been of some service lately in another direction. The Council was asked in February by General Sir O'Moore Creagh, V.C., Military Adviser to the Central Association of Volunteer Training Corps, to co-operate in the formation of an Engineer Unit which should be affiliated to the Central Association, and after circularizing the members in the London district in the first instance, we obtained such a response that it was felt we could well form a nucleus Engineer Unit. A meeting was held last week of those who had signed the forms, when I had the honour of addressing them, and we then handed them over to the Commandant, Lieutenant-Colonel C. B. Clay, a very well-known telephone and telegraph engineer and a Member of the Institution. They have also done me the honour of making me the Honorary Commandant, of which I feel very proud. During the earlier part of the session the Council appointed a Committee to keep in touch with the British Electrical and Allied Manufacturers' Association in regard to the question of securing for the British electrical industry the trade of Germany and Austria-Hungary. A number of meetings were held, and after a very full consideration of the matters which were put before them the Committee came to the conclusion, with the concurrence of the manufacturers' representatives, that the continuance and expansion of British trade after the war would mainly depend on economic principles and on the commercial industry and initiative of British manufacturers, and that no useful action on the part of the Institution appeared to be possible. An important Committee has been sitting, for the purpose of dealing with the question of the periods for the repayment of municipal loans, and the Council to-day has passed a draft memorial to the Local Government Board, which will be forwarded in due course, and may be followed by a deputation, and it is hoped that certain concessions will be given which will be helpful to municipal interests. I may also say that, as President of the Institution, I am now associated with the Presidents of the Institutions of Civil Engineers and Mechanical Engineers in making a representation to the Treasury and to the Local Government Board in connection with the regulation of loans to municipalities, and the regulation of public works, and it is possible that some useful work may also be done in that respect. We have just concluded, before the opening of this Annual General Meeting, the Annual Meeting of the Committee of Management and the subscribers of the Benevolent Fund. It will be recollected that quite recently I issued an appeal to the members of all classes, except Students, for subscriptions and donations to this Fund, but I must say I feel that the response was totally inadequate to meet the requirements of the Fund. I know the criticism has been levelled against the Fund that the outgoings are so small that there is no real necessity to expand the income ; but that idea is quite wrong. As I stated in my appeal, there were at that time three, and there are now two, very important cases before us in which, if anything like adequate support is to be given, a very substantial annual contribution must be made, and such a substantial contribution cannot be made from the funds at present at the disposal of the Benevolent Fund

[illegible]

[illegible] removing that feeling, which I know exists in some quarters. The last matter to which I wish to [illegible] is the Benevolent Fund. I cannot help thinking that this question has not been brought to the attention of members in the way that it should. The appeal recently made by the President was [illegible] direction, but evidently did not do all that he hoped it would do. It must be remembered, [illegible] that the present is a very difficult time, and I suggest that when times get more normal a little more pressure on [illegible] not have time to read. I agree with the President that the present state of the Benevolent Fund is [illegible] unworthy of the Institution, and I hope that some way will be found of giving it a little more publicity when the time arrives that we are in a position to respond more freely to appeals made to us.

Professor J. T. Morris: I should like to ask for further information with regard to the [illegible] regulations are more stringent, so that more candidates have been rejected. I see that the numbers come [illegible] not giving technical matters as much attention as usual, and this may account for the large decrease of 133. [illegible]

Mr. S. Evershed: There is, and always has been ever since I have been a member, a feeling among the [illegible]

names put forward. But even so there is room, I cannot help thinking, for some machinery by which more names of useful men might be brought to the notice of the Council at the time when nominations are being considered, and I was going to make this suggestion :—No one can serve on the Council for a number of years without realizing more clearly what are the qualities which go to make up a useful Member of Council, and it seems to me it might be possible to arrange for past Members of Council to be asked to suggest one or two names every year for the consideration of the Council in drawing up their list of nominations. If this were done, the Council might intimate from time to time what particular section of the industry appeared to be inadequately represented, and in this way a flow of new names would come in without in any way trenching on the duty of the Council in putting forward the list.

Mr. J. F. Shipley : I should like to know why the Scottish Students' Section held no meetings during last session.

Mr. W. M. Mordey : It is a very sad state of things that, after all these years of work, the Benevolent Fund is not in a better position. I find that the actual contributions for the year average less than 6d. per member. An increase in the Fund is wanted for the urgent necessities of deserving people. The Fund could be made worthy of this Institution by small regular contributions of a few shillings from members generally. Everybody, Students included, could easily answer the application that is sent out by the Secretary every year by a promise to contribute some small sum. Many members do not like to contribute unless they can contribute gold, but I think the management of the Benevolent Fund would be very happy indeed if they could get, say, an average of half a crown per annum per member. That would put the Fund in the position it ought to be in—the position of being able to help cases that are often pitiable in the extreme. May I supplement what you, Sir, have said by a very earnest appeal to members generally to make a special effort to give this Fund some small sum annually and regularly?

Mr. W. R. Rawlings : Following on Mr. Mordey's remarks, I may say that I intended speaking on the same subject in a similar strain. In the first place, I should like to refer to the Accounts themselves. I suggest that they should be made up in a different form. A sum of £439 is brought forward and placed under the heading of "Receipts," making the total appear larger than it really is. It is perfectly true, as Mr. Mordey pointed out, that a very small sum indeed has been contributed during the past year by members. I think also that much has been lost owing to members feeling that they ought to send gold in response to the appeal. I suggest that if an appeal were sent on the following lines : "Will you promise an amount not exceeding 5s.," 90 per cent of the members would respond to it.

Mr. F. C. Raphael : I am heartily in agreement with what Mr. Mordey and Mr. Rawlings have said with regard to small contributions to the Benevolent Fund. I think everyone will agree that a large amount might be realized by suggesting in the notice sent out to all the members that they should contribute a small minimum subscription ; but I think that, in addition, what Mr. Mordey called the gold contribution could be encouraged—possibly in a different manner. If a fairly large Committee were formed of influential men in the Institution, and if they were induced to write personal letters to their friends and to make personal efforts in collecting contributions, instead of printed forms merely being sent out, I feel sure the results would be very satisfactory indeed in what Mr. Mordey calls the gold contribution. I also think that some of the richer electrical firms might be approached through their heads who are members of the Institution, to give very large sums—much larger sums than the majority of the donations and subscriptions which are now given. There is one point to which I should like to allude arising indirectly out of the Report. Mention has been made of the very fine way in which the members have responded to the call of the Army and Navy. I think it would be an appropriate act on the part of the Institution if they could find some way to relieve those members of the obligation of paying their subscriptions for the period during which they are on active service. I do not know whether it is possible to do so in our case, but I believe it has been done in a great many other Institutions—certainly it has been done in almost every Club in the United Kingdom.

Mr. A. Home-Morton : Is there any particular reason why a small percentage should not be added to the amount of the subscription, such percentage being devoted automatically to the Benevolent Fund? That is done in one Association, of which I have the honour to be President, and it would not prevent those who wish for greater publicity from sending large sums. I certainly think there is no member who, if the question of the Benevolent Fund were properly put before him, would object to having a small sum added to his subscription, for this very worthy purpose.

The President : I will answer in as few words as possible the questions which have been put. Mr. Atkinson referred to the publication of a list of the Committees, and also of the attendances of the members upon those Committees. That is a matter in which I must be guided by the Council, but I promise that it

[illegible]

The resolution was then put and carried unanimously.

[illegible] Balance Sheet for the past year.

[illegible]

consequence of the examinations. We are seeking for a very much better class of member. We were told that by putting such stringent regulations into operation we should practically stop the flow of new members, but we elected as many as 171 in the past year. To return to the accounts, we had a net decrease in income of £994 and, owing to there being every year a greater call upon the Finance Committee for increasing the work of the Institution, an increase of £215 in the expenditure, those two figures accounting for the £1,209 difference to which I have already referred. Our Life Composition Fund stood on the 1st January, 1914, at £5,506. We have now adopted the principle of transferring from the Life Composition Fund the amounts of the life compositions of members deceased during the year. In former years we used to leave those amounts in the Fund, which did not seem to be right when all obligations had ceased, and under our revised Articles of Association we obtained power to transfer such amounts. We transferred in that respect £97 last year, leaving to the credit of the Fund £5,409. The Building Fund during the year has been increased to the extent of £41 18s. od. by donations and subscriptions, and there has been a contribution out of the Institution Funds of £667, a total of £709, which amount was used in reduction of the mortgage. Referring to our total assets and liabilities, this is how we stand. I draw attention to the fact that as we are not a trading concern we do not make a valuation of our assets every year, and we take our investments, year after year, at their book values, at their cost, and with that reservation our position is this. Our assets amount to £114,929 and our liabilities to £43,359. We have therefore a margin to the good of £71,569. This time last year our margin to the good was £69,523, so that we are better off, as far as our margin to the good is concerned, to the extent of £2,046. I have pleasure in moving "That the statement of Accounts and Balance Sheet for 1914, as presented, be received and adopted."

Mr. J. S. Highfield: I have pleasure in seconding that motion.

Mr. W. B. Esson: There is one point that I should like to refer to in the Balance Sheet. The first item on the assets side is the cost of the building. Then the item appears: "Less reserve for depreciation, being sinking fund premiums paid." I wish to point out that that is not strictly accurate. The value of the depreciation fund is not the amount of the sinking fund premiums paid, but the surrender value of the sinking fund policy on the 31st December, which is a slightly different thing. It is a point which is more or less academical, but I thought I should like to mention it. Then as to the liabilities side, I would ask the Honorary Treasurer a question as regards the Trust Funds Capital Accounts for the David Hughes and similar Scholarships. Are we, as an Institution, responsible for those funds being maintained at their original value? By putting them in the general Balance Sheet, as they are now, it would seem as if we were. If not, they ought to be taken out of the general Balance Sheet and a separate Balance Sheet made for each of them.

Mr. R. Hammond: For a great many years we set out the Trust Funds separately from the Main Accounts, but a few years ago we thought that it would be more convenient to have all the Accounts under one heading. Possibly those who set them out separately had a good reason for doing so, but I must say it never occurred to me that, by the inclusion of them in the main Accounts, we in any way took the responsibility of maintaining them at their face value. Indeed, in the case of some of them, the bequests were made in stock. As the question has been raised, I certainly think that we shall have to ask our Solicitors whether it would not be better to put them at the end of the general Accounts as we used to do. Mr. Esson is quite correct in stating that the total amount of the sinking fund premiums at any time cannot be taken to measure the amount of depreciation of the lease of the Institution buildings. In my Annual Report to the Council I always draw attention to that fact. Here again we do not act as if we were a trading concern. The actual position is that the Institution holds policies for £75,000 which, if the premiums are kept up, will eventually wipe off the cost of the lease and our expenditure on the buildings. A time will come when the surrender value of the premiums will exceed the amount of the total premiums paid on account of the compound interest thereon. Hitherto we have not deemed it necessary to erect a further depreciation fund, in addition to the amount of the sinking fund premiums, to provide for the decreasing value of the lease and building, but the Council will doubtless reconsider the point before the publication of the next Accounts.

Mr. L. B. Atkinson: I agree with Mr. Esson that the trust funds are not part of the general accounts. I am a little confused, moreover, because I see that in the Trust Funds Capital Accounts, on the liabilities side, the David Hughes Scholarship is entered as £2,000, and on the other side there is an investment shown of £1,998 15s. od., which differs by 25s. from the amount on the other side. Why does it not balance as the other trust funds do?

[Mr. Hammond explained that the uninvested balance of £1 5s. od. on the David Hughes Scholarship

[illegible]

The resolution for the adoption of the Accounts was then put and carried unanimously.

Mr. R. T. Smith: I have pleasure in proposing the following resolution: "That the best thanks of the Institution be given to the Honorary Secretaries of the Local Sections and the Local Honorary Secretaries and Treasurers abroad for their kind services during the past year."

Mr. W. H. [illegible]: I have much pleasure in seconding that resolution.

The resolution was put and carried unanimously.

Mr. J. E. [illegible]: The resolution which I have the pleasure to move is: "That the best thanks of the Institution be given to Mr. Robert Hammond in recognition of the valuable services rendered by him as Honorary Treasurer of the Institution during the past year." [illegible] Mr. Hammond [illegible]

Lieutenant-Colonel C. H. Clay: I have much pleasure in seconding that resolution.

The resolution was then put and carried unanimously.

Mr. C. H. Wordingham: I have much pleasure in moving: "That the best thanks of the Institution be accorded to the Honorary Auditors, Mr. H. Alabaster and Mr. Sidney Sharp, for their kind services during the past year."

Mr. W. R. Cooper: I have much pleasure in seconding that resolution.

The resolution was put and carried unanimously.

Mr. W. Duddell: I beg to propose: "That the best thanks of the Institution be accorded to Messrs. Bristows, Cooke, and Carpmael, for their kind services in the capacity of Honorary Solicitors to the Institution during the past year."

Mr. H. M. Sayers: I have much pleasure in seconding that resolution.

The resolution was then put and carried unanimously.

The President: I now have to ask the meeting to appoint two Honorary Auditors for 1915–16. The present Auditors, Messrs. H. Alabaster and Sidney Sharp, are eligible for re-election. Both gentlemen know all about our accounts, and have acted for us for several years. Will somebody propose their re-election?

Mr. [illegible]: I have much pleasure in proposing: "That Mr. H. Alabaster and Mr. Sidney Sharp be elected Honorary Auditors for the year 1915–16."

Mr. W. R. Rawlings: I beg to second that resolution.

The resolution was then put and carried unanimously.

The President: [illegible] and that things may be better than they appear to be at the present time. I hope we shall meet in happier times.

The meeting adjourned at 9.20 p.m.

BENEVOLENT FUND.

REPORT OF THE COMMITTEE OF MANAGEMENT FOR THE YEAR 1914.

CAPITAL.

The Capital Account stood on the 31st December last at £4,642 3s. od., all of which is invested.

INCOME.

The Statement of Accounts (see page 735) shows that the total receipts during 1914 were as follows:—

	£	s.	d.
Dividends on Investments	160	7	10
Interest on Deposit	3	8	4
Annual Subscriptions	72	9	6
Donations of £5 and over	92	10	0
Donations under £5	14	19	6
	£343	15	2

SUBSCRIBERS AND DONORS IN 1914.

ANNUAL SUBSCRIBERS.

H. Alabaster.
G. F. Allom.
A. B. Anderson.
I. Braby.
S. E. Britton.
R. A. Chattock.
V. K. Cornish.
B. Davies.
Sir A. Denny, Bart.
J. Devonshire.
H. C. Donovan.
B. M. Drake.
C. V. Drysdale, D.Sc.
W. Duddell, F.R.S.
K. Edgcumbe.
S. Evershed.
F. Gill.
J. Gillingham.
R. T. Glazebrook, C.B., D.Sc.
B. B. Granger.
R. K. Gray.
F. E. Gripper.
C. W. Gwyther.
H. T. Harrison.
C. C. Hawkins.
K. Hedges.
D. Henriques.
J. S. Highfield.
H. Hirst.
E. S. Jacob.
H. W. Kolle.
A. E. Levin.
J. R. P. Lunn.
E. de M. Malan.
Sir H. C. Mance, C.I.E.
J. W. Meares.
L. B. Miller.
W. M. Mordey.
W. M. Morrison.
F. H. Nicholson.
A. M. Ogilvie, C.B.
E. Parry.
The Hon. Sir C. A. Parsons, K.C.B.
W. H. Patchell.
C. C. Paterson.
A. H. Preece.
W. L. Preece.
W. R. Rawlings.
T. Rich.
R. R. Robertson.
S. R. Roget.
S. A. Russell.
S. G. C. Russell.
Sir David Salomons, Bart.
S. Sharp.
A. Siemens.
F. Smith.
Sir John Snell.
C. P. Sparks.
A. Stroh.
A. J. Stubbs.
W. C. P. Tapper.

ANNUAL SUBSCRIBERS—*continued.*

A. M. Taylor.
C. H. R. Thorn.
J. H. Tonge.
A. P. Trotter.
T. C. T. Walrond.
W. B. Woodhouse.
C. H. Wordingham.

DONORS.

The Associated Municipal Electrical Engineers of Greater London.
J. F. Avila.
T. H. Barr.
The "25" Club.
The Electrical Engineers' Ball Committee.
The General Electric Company, Ltd.
S. Hill.
A. Russell, D.Sc.
Sir David Salomons, Bart.
H. C. Silver.
C. W. Speirs.
A. M. Taylor.
G. W. Warner.

At the end of March 1915, in view of the cases then before the Committee and of other cases likely to occur in the near future, the President was authorized by the Council of the Institution to make an appeal to the members of all classes of the Institution for subscriptions and donations to the Fund. The result of this appeal (up to the 27th May) was as follows :—

	£	s.	d.
37 Annual Subscriptions	43	3	6
44 Donations	321	1	6

The Committee of Management desire to acknowledge their indebtedness to the generosity of the donors and subscribers who have supported the Fund, but in view of the inadequacy of this result, the Committee venture once more to urge upon the members the pressing need for a more generous response to the President's appeal, and desire to add that, apart from donations, the Committee of Management will be grateful for annual subscriptions, even of quite small amounts.

GRANTS.

Ten applications for assistance were received in 1914, and the Committee, after due investigation, made grants in all the cases. Six grants were made of £10 each, one of £8, one of £6 2s. 6d., and two of £5, a total of £84 2s. 6d. for the year.

WILDE BENEVOLENT FUND.

The Capital Account stood on the 31st December last at £1,846 4s. 6d., the whole of which is invested and brings in an annual revenue of £55 17s. od.

The Balance standing to the credit of the Income Account at the end of 1914 was £367 os. 1d., of which £345 14s. 8d., was invested.

No grant from this Fund was made during the year.

OBITUARY NOTICES.

WILLIAM [illegible] ADAMS [illegible]

[illegible]

JOHN FRANCIS [illegible] [illegible] Messrs. Crompton & Co., and was for some time managing director. He subsequently became managing director [illegible] Company and a director of the Birmingham Electric [illegible] He was elected a Member of the Institution in 1885.

CHARLES [illegible] HALL [illegible] 1914, at Leeds, at the age of 53. He was one of the [illegible] College, and then passed some time in the Appold-street [illegible] subsequently served as electrical engineer on board the [illegible] works. In [illegible]

[illegible] Eastbourne and West [illegible]

EDWARD J. HALL [illegible] he became vice-president and general manager, and in 1885 he took charge of the development of the American Telephone and Telegraph Company. [illegible] can Telephone and Telegraph Company [illegible]

ROBERT HOPE-JONES was born in [illegible] Grange, Cheshire. After serving his apprenticeship with Messrs. Laird Brothers, Birkenhead, he [illegible] and with the help of [illegible]

of North Fonnawanda. He died at Rochester, N.Y., on the 13th September, 1914. He was elected a Member of the Institution in 1892.

JOHN NASSAU CHAMBERS KENNEDY, Major R.E., was born in Canada in 1864 and received his first commission in the Army in 1886. Throughout the South African War he served on the Staff in connection with telegraph and wireless telegraph work, and was mentioned in despatches. After the war he returned to this country and was appointed assistant instructor at the School of Military Engineering, Chatham. He retired from the Royal Engineers in 1910 and took charge of the electric signalling work of the London and North-Western Railway Company. At the outbreak of war in August 1914 he was called up from the Reserve and undertook the work of organizing the telephone systems of the new camps. A few months later he had to go into hospital and he died at Rugby in April 1915. He was elected a Member of the Institution in 1899.

HATSUNE NAKANO, Professor of Electrical Engineering at the Imperial University, Tokio, Japan, died on the 16th February, 1914. He was born in January 1859, and in 1874 entered a preparatory school for the Engineering College in Tokio. In 1881 he graduated from the Government Engineering College, obtaining the degree of Master of Engineering. He was at once appointed Assistant Professor of the College. In 1888 he visited England and the United States. On his return he was promoted to a professorship, and in 1899 was granted the degree of Doctor of Engineering. In 1909 he was again sent to Europe and the United States, visiting various works, electrical plants, and colleges. In 1913 he was appointed a member of the Council of the Imperial University, Tokio, at which University he lectured for over 33 years. A few years ago when the Japanese Electrical Society was reorganized, he was elected president. He was Chairman of the Committee responsible from time to time for drawing up Government regulations dealing with the use and generation of electrical energy, and he was also Chairman of the Japanese Electrotechnical Committee. He was elected a Foreign Member of the Institution in 1884, becoming a Member in 1911. S. Y.

SAMUEL WILMOTT NEWINGTON was born on the 4th November, 1868, at Goudhurst, Kent, and was educated at the Grammar School, Sutton Valence, Kent. He received his electrical engineering education at the City and Guilds of London Technical College, Finsbury, taking the day course during two years and attending the evening classes for one session. In 1888 he entered the service of the Pacific and Oriental Steam Navigation Company, serving for 16 months as electrical engineer on board the s.s. *Pekin* and the s.s. *Rome*, and then for over two years having charge of the Company's searchlight plant in use on the Suez Canal. In March 1892 he was appointed assistant engineer at the Millbank-street station of the Westminster Electric Supply Corporation, being transferred a few months later to the Company's Eccleston-place station. In January 1893 he was appointed chief electrical engineer and manager of the Oldham Corporation electricity supply undertaking, a position that he held for over 21 years, until his death, which occurred on the 13th July, 1914. He was elected a Member of the Institution in 1913.

CHARLES WHENSA NICHOLL was born in November 1873. He received his technical education at Durham College of Science from 1891 to 1893, and then served an apprenticeship with Messrs. J. H. Holmes & Company. He left this firm in 1897 in order to become assistant engineer to the Brush Electrical Engineering Company, and a year later he became private assistant to Professor J. A. Fleming. In 1900 he was appointed Engineer and Manager to the Northallerton Electric Light & Power Company, but returned to London a year later on receiving an appointment on the staff of Mr. A. A. C. Swinton. In 1901 he was appointed engineer to Messrs. Kilburn & Company and Acting Engineer to the Calcutta Electric Supply Corporation, and was connected with the design and erection of the power station for the Durbar Camps at Delhi in 1902–3. In 1904 he was again for a short time on the staff of Mr. A. A. C. Swinton before obtaining an appointment as engineer with Messrs. Harper Brothers. At the time of his death, which occurred on the 1st December, 1914, at Port Said, he was on his way to India, having been engaged by Messrs. Alfred Dickinson & Co. in connection with the Tata hydro-electric scheme. He was elected an Associate Member of the Institution in 1902, and a Member in 1911.

STUART RICHARDSON was born in Swansea on the 9th January, 1863. For some time he studied law, but a legal career did not appeal to him. He served his time with the Brush Company at Loughborough, and then for three years was superintendent at the Leicester Corporation Electric Lighting Works. In 1899 he accepted an appointment with the New Zealand Electrical Syndicate, a private company which at the time provided the electric lighting of Wellington, New Zealand. In 1902 he was appointed assistant tramway engineer and in 1905 tramway and electrical engineer to the Wellington City Corporation, N.Z., a position he held until his death, which occurred on the 11th September, 1914. He was elected an Associate of the Institution in 1895, an Associate Member in 1899, and a Member in 1901.

ROBERT ORD RITCHIE died on the 29th January, 1915, at Battle, Sussex. He served his apprenticeship as a mechanical engineer with Messrs. Pearce Brothers of Dundee, and was subsequently employed by Messrs. Samuel Lawson & Sons of Leeds, Messrs. Carmichael & Company of Dundee, Messrs. John Fowler & Company of Leeds, and the General Ice Factory Company of London. In 1883 he joined Messrs. Woodhouse & Rawson, becoming later their Contract Manager. In 1884 he became a member of the firm of Messrs. Thompson, Ritchie & Company. He was later associated with Messrs. Scott & Mountain, and subsequently became Manager of the electrical department of Messrs. Greenwood & Batley. In 1908 he retired to Battle, in Sussex. He was elected an Associate of the Institution in 1887, and a Member in 1897.

GEORGE PATRICK ROBERTSON was accidentally drowned, at the age of 45, in Rungeet River, Darjeeling, India, on the 18th January, 1915, whilst engaged

[illegible]

[illegible]

[illegible] Secretary of the Admiralty Committee on the electrical [illegible] staff appointments until he received the command of the [illegible]

JOHN MATTHIAS AUGUSTUS STROH died at his [illegible]

[illegible] the far more convenient telephone. The most important however, of these joint inventions was what is known as [illegible] premises in London which he converted into a factory [illegible] were, in the year 1880, taken over by the Post Office, for [illegible] to retire from business and to devote the whole of his energies to original work in connection with almost every [illegible]

liquid demonstrating, in a most remarkable manner, an analogy between those phenomena and those of electricity and magnetism. This was pre-eminently a subject that would appeal to Mr. Stroh's love for a physical research which required the construction and use of especially delicate apparatus, and Mr. Stroh immediately took up the subject, and by means of the most exquisite apparatus, entirely constructed by himself, he extended the research and demonstrated the phenomena without the use of viscous fluids but in air at ordinary pressures. Mr. Stroh brought these experiments before the Institution in a paper in which he treated the subject in a most exhaustive manner, which was read at the meeting held on the 27th April, 1882, and of which the following was the title, "On Attraction and Repulsion due to Sonorous Vibrations, and a Comparison of the Phenomena with those of Magnetism" (*Journal of the Society of Telegraph Engineers and Electricians*, vol. 11, p. 192, 1882). This paper excited the most intense enthusiasm. The late Colonel Webber was President, and an interesting discussion followed in which the following Members took part: the late Professor Guthrie, the late Sir William Preece, and Professor George Forbes.

Mr. Stroh contributed only one other paper to the Institution, namely, "On the Adhesion of Metals produced by Currents of Electricity," which was read on the 14th April, 1880, during the Presidency of the late Sir William Preece (*Journal of the Society of Telegraph Engineers*, vol. 9, p. 182, 1880), but he gave the Institution the benefit of his experience on many occasions. Mr. Stroh was, however, of so modest and retiring a nature that he could only be induced to speak when from his special knowledge of a subject he could add to the value of the discussion.

Mr. Stroh was a distinguished horologist, and had at his house a magnificent collection of watch and chronometer movements embracing every variety of escapement and exhibiting refinements of construction for eliminating errors of every description. In early life he constructed with his own hands a watch of high quality, the dimensions of which, *i.e.* diameter and thickness, were the same as those of a half-crown, and this he presented to Sir Charles Wheatstone, in whose family it has remained ever since. In 1860 Mr. Stroh devised a system of electric clocks whereby a number of dials were worked from a parent or motor clock. The dials were actuated by continuously revolving astatic galvanometers synchronously driven by alternating currents transmitted by the pendulum of the motor clock. An especial feature of this clock was the very beautiful almost frictionless escapement, the pallets being in the form of anchors which made a rolling contact with the teeth of the 'scape-wheel. Mr. Stroh was a man who never touched a thing without improving it, and soon after the introduction into this country of the phonograph he constructed an instrument entirely in aluminium which has never been excelled for perfection of performance, for uniformity of speed, and for silence in its mechanical working. This was due to two features, the perfection of workmanship and the extraordinary efficiency of the governor which regulated the speed. Acoustics and the analysis of musical notes occupied much of the interest and work of Mr. Stroh. As far back as 1872 he devised a musical instrument the notes of which were produced by a single vibrating tongue or reed, the effective length of which was controlled by a set of keys arranged on a finger-board, and so delicate was it in its action that the various notes produced were musically pure and extended over three octaves. He also constructed an instrument for analysing and recording on paper the successions of sonorous vibrations set up by a piece of music performed by an orchestra, a chorus or a vocalist. He showed this as one of the illustrations to a discourse he gave at the Royal Institution at one of the Friday evening meetings, on the 17th February, 1879, its title being "On Studies in Acoustics: a Synthetic Examination of Vowel Sounds." Another subject in which Mr. Stroh excelled was photography, and it would be difficult to say if he most excelled in landscape work, in portraiture, in stereoscopy, or in the production of photographs in their natural colours, for he was always up to date; and the apparatus he used was nearly always designed and constructed by himself.

Besides being a Member of the Institution he was also a Member of the Physical Society, of the Royal Institution, of the Camera Club, and of the Société Internationale des Électriciens, and he served on the juries of awards at several of the international exhibitions. He was one of the most modest and retiring of men, and there can be but little doubt that but for these admirable qualities he might have received the highest honours in this and other countries; but he was honoured and beloved by all his friends, who knew his worth and admired his character. He was one of the central figures in a little coterie which used to meet for their midday meal three times a week, first at "The Horse Shoe" and more recently at Frascati's. This little group of genial companions was composed of the late Professor Hughes, Mr. Buckney, our late Secretary, Mr. F. H. Webb, Mr. Heaviside, Mr. Horton, Professor Spooner, and Mr. Conrad Cooke, and was often joined by the late Sir William Preece and by Professor George Forbes. By Mr. Stroh's death this little society must necessarily cease to exist, but his memory will long be cherished with affection by all who had the privilege of his friendship. He was married to a Miss King, who died some years before him, and he left one son and two daughters. He was buried in Hampstead Cemetery.

C. W. C.

WILLIAM GRIGOR TAYLOR was born at Newhills in 1847, and received his early education in Aberdeenshire. On leaving Aberdeen University in 1865 he came to London, and after doing clerical work for a few years obtained an appointment in 1869 with the Telegraph Construction & Maintenance Company. Whilst with that company he took part in several cable-laying expeditions. In 1873 he joined the Eastern Telegraph Company, and in 1875 was appointed Superintendent at the La Perouse station, Sydney, of the Eastern Extension, Australasia, and China Telegraph Company, becoming General Manager at Singapore in 1883. He held that appointment until he returned to England in 1902. Shortly afterwards he went to New York as the representative of the Eastern & Associated Companies. Early in 1914, owing to ill-health, he came back to England, and he died at Bournemouth on the 19th November, 1914, aged 67 years. He was elected an Associate of the Institution in 1872, and a Member in 1902, and was Local Honorary Secretary for the Straits Settlements from 1902 to 1904.

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